Unlocking participation

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The dynamics of opening up and closing down in emerging technologies

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UNLOCKING PARTICIPATION

The dynamics of opening up and closing down in emerging technologies

Dissertation

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Part I

Problem outline, research frame and methodology

1. Introduction: Governing emerging technologies

Science and technology are among the most influential factors shaping modern societies during the last centuries. Scientific research and technological progress promise to ensure economic prosperity, to address societal challenges, and to improve human life in general. At the same time, they are repeatedly blamed for profound societal and environmental problems: the grand societal challenges of our time like climate change and environmental pollution are deeply rooted in the progress of science and technology. And then, in another twist, science and technology play a key role in the response to these challenges. The sociologist Ulrich Beck (1992) called the condition of science and technology constituting cause and salvation of problems alike a "double bond". This ambivalence of scientific and technical progress provokes questions about how their risks and benefits are distributed among society: consequences of science and technology affect people involved in decision-making as well as members of society without a say in that regard. Thus, social, scientific, and technical questions are closely intertwined: visions of a desirable future concern fundamental ethical and social values, including questions of distributing (ecological and economic) risks, solidarity and social cohesion, fairness, equality, and justice. Accordingly, technologies should not only be developed to fulfill specific tasks. Rather, to address these issues, questions of responsibility in their development, and reaching societal acceptance for them as broadly as possible are brought to the fore.

To do so, striving for a variety of societal voices in decision-making sets out to ensure safe, just, democratically justifiable, and socially robust decisions for science, technology and innovation (STI) governance. In the last decades, science and technology have been criticized for inadequately aligning with overall societal objectives and values, such as sustainability or responsibility (Owen et al. 2013, von Schomberg 2013). Especially new and emerging technologies, such as nanotechnologies, synthetic biology or artificial intelligence put a lot at stake since they often evoke exorbitant expectations (for analyses of the social life of expectations see e.g., van Lente 2012, Borup et al. 2006, van Lente and Rip 1998). Emerging technologies are inherently ambiguous and trigger ideas about potential future applications and consequences that raise hopes as well as fears. Thus, they give rise to a range of different value-laden perspectives and patterns of moral argumentation (Swierstra 2017, cf. Swierstra and Rip 2007).

In STI governance, the exchange of perspectives between actors increasingly constitutes an important strategy to overcome this ambiguity. Accordingly, engaging societal stakeholders and the wider public became in vogue to ensure a comprehensive reflection on emerging technologies, to better align them with societal values, and to address and counter democratic deficits in their development (e.g., Burri 2018, Chilvers and Kearnes 2016, Owen et al. 2013, Kearnes, Macnaghten, and Wilsdon 2006).

Meanwhile, societal engagement has become widely adopted with an increasing "variety of new institutions, processes, and tools" (Stirling 2008, 263). One could think of participation and societal engagement as a way to *unlock* how we design STI governance. Indeed, societal engagement with emerging technologies features several pertinent promises, as Delgado, Kjølberg, and Wickson (2011) pointed out. It sets out to enhance social robustness of decisions and to ease democratic shortcomings of STI governance and promises a more inclusive process compared to scientific analysis by offering a more comprehensive variety of perspectives, e.g. in policy advice (Delgado, Kjølberg, and

Wickson 2011, Stirling 2008). Thus, societal engagement constitutes a popular strategy in technology policy, STI governance, and innovation more generally to arrive at widely acceptable and accepted decisions, and to ensure innovation (Owen, Macnaghten, and Stilgoe 2012, van Mierlo, Beers, and Hoes 2020). Moreover, it is supposed to strengthen agency with regard to STI governance. This is where my thesis sets in.

My thesis is anchored in two observations: first, that participation and societal engagement have become a well-known factor in STI governance in the last decades, and second, that in spite of their popularity, the actual processes and achievements of participation and societal engagement are not yet fully understood. In fact, scholarly debates about their tangibility, their efficacy and concrete merits for research and innovation are ongoing: participation and societal engagement may, for instance, sketch out alternative technology pathways and policy options, enrich the options already on the table, or point to hitherto unconsidered overall solutions (e.g., Stirling 2008). At the same time, some scholars argue that they are but one way of organizing public space and, although omnipresent, still run into a range of conceptual and practical challenges (e.g., Voß and Amelung 2016, Delgado, Kjølberg, and Wickson 2011). And others, again, point out that it is far from clear whether and how participation and societal engagement contribute to STI governance (e.g., van Oudheusden 2014).

Inspired by these ambiguities of participation and societal engagement, my work aims to *unlock participation and societal engagement* themselves. Like a door, they structure the metaphorical space: they provide a 'frame' for STI activities, grant or deny access, and actively shape STI governance. At the same time, participation and societal engagement are variable and dynamic as access is a matter of gradation: a door can be locked, opened wide or just ajar. Hence, the ways in which participation and societal engagement are constituted, vary – and accordingly, do the ways in which agency is enabled or constrained.

One particularly prominent way of conceptualizing the inherent ambiguities of participation and societal engagement in the last two decades has been offered by Andy Stirling (2008). He proposes that decisions in STI governance require both 'opening up' and 'closing down'. This paradox frames the very interest of this thesis. Taking Stirling's conceptual apparatus as a starting point and a language for analyzing the challenges inherent in organizing meaningful, robust and participatory STI governance, I will examine when and how 'opening up' occurs in societal engagement, and when and how such efforts 'close down' STI governance. I will trace how opening up and closing down enable or constrain agency, and how this is related to engagement settings and temporalities. By investigating the dynamics of opening up and closing down, my thesis is located at the intersection of governance, technology assessment, democratization of science, and co-production.

My specific interest in opening up and closing down sheds new light on a rich tradition of studying and facilitating participation and societal engagement. Increasing reflection, and eventually altering of, science, technology development, and innovation has been addressed in various ways. Well-established approaches to integrate mechanisms of reflection in STI and STI governance are the approach of mid-stream modulation (Fisher, Majahan, and Mitcham 2006), as well as constructive technology assessment or real-time technology assessment (Schot and Rip 1997, Guston and Sarewitz 2002), aimed at enhancing reflection and social experimentation in STI practices along the technology or

innovation pathway. Opening up and closing down add a specific analytical focus in the debate on emerging technologies. They construct participation and societal engagement in relation to (scientific) analytical approaches by considering them as equivalent, yet functionally different and allow to account for structural aspects in the analysis of STI and STI governance.

At the very core of my research interest are the *dynamics of and mutual dependencies* between opening up and closing down. I will address these dynamics in various empirical, theoretical and practical ways, to be elaborated below. My research will be guided by the following questions: How do phenomena of opening up and closing down mutually define, enforce or hinder each other? How do the dynamics of opening up and closing down play out in different STI settings and temporalities?

I structure my research in three parts, with nine chapters in total. *Part I sets the scene for the thesis*. It introduces the reader to participation and societal engagement, as well as to the research frame of the overall thesis. Also, methodology and empirical details will be prepared. The task division is as follows:

- Chapter 2 anchors my work in the context of participation and societal engagement. Here, I summarize the story of how they became normalized in technology debates (section 2.1). In particular, I present presumptions of participation and societal engagement (section 2.2), including assumptions of democratic theory – in particular with regard to the role of expert knowledge in deliberative theory. Moreover, I discuss challenges and tensions in relation to participation and societal engagement in STI governance as they shape my empirical work (section 2.3).
- Chapter 3 presents the analytical frame of my thesis. I start by introducing opening up and closing down, with particular reference to Stirling (2008) as a starting point for my reflection (section 3.1). To broaden my perspective, I trace how Stirling (2008) has been mobilized in STS and sustainable transition literature (section 3.2). I then formulate my research questions (section 3.3). To address them, I define three dimensions for my empirical analysis, conceptualizing the relations between opening up and closing down in detail, and reveal the theoretical assumptions of my thesis.
- Chapter 4 describes the overall research design and method of my thesis in detail. I selected a case-study approach (section 4.1) where each case study represents a specific 'moment' alongside the innovation stream. I shortly characterize each case study (section 4.2) and explain the background conditions of gathering data in the respective research projects (section 4.3). Moreover, this chapter reports procedures of collecting and handling data, and applied methods of analysis (section 4.4).

Part II presents my empirical work. As this is a cumulative thesis, each empirical chapter constitutes a part of this thesis as well as a stand-alone contribution to the discussion on the respective technology (neuroenhancement, synthetic biology, nanomaterials). Each of these empirical domains will be studied from a specific angle, to do justice to the breadth of the topic.

- Chapter 5 investigates myth formation in neuroenhancement as a way of early-upstream public sense-making.

- Chapter 6 analyzes engagement of civil society organization on synthetic biology in relation to different engagement formats and framings of the debate.
- Chapter 7 studies the affordances of a specific computational modelling tool for risk governance of nanomaterials.

Part III provides the overall analysis of opening up and closing down before drawing conclusions.

- Chapter 8 analyzes the phenomena of opening up and closing down in the case studies through three analytical dimensions (social, epistemic, normative). It examines the case studies individually (section 8.1), as well as across case studies (section 8.2), and reflects on how each of the perspectives studied could enrich reflection of STI and STI governance more generally (section 8.3).
- Chapter 9 features the lessons of this thesis. It presents the insights on the dynamic relations between opening up and closing down (section 9.1). In addition, I also share insights on discourse and dialogue to better anchor my findings on participation and societal engagement on a practical level (section 9.2).

2. Participation and societal engagement: making science, technology and innovation governance more inclusive

The proclaimed hope of participation and societal engagement in the development of new technologies is to render STI governance more inclusive. However, in theory as well as practice, such aims encounter a range of challenges. This chapter will review attempts at participation and societal engagement of the last half century – and how they empower the agency of a broad range of actors. This overview provides the basis for my own interest, which will focus on how dialogue, and by extension agency, is constituted in the context of emerging technologies. In this literature review, I draw from various research fields within policy studies and science and technology studies (STS), such as the governance of emerging technologies and risks, science policy, and democracy in science. In particular, I introduce technology assessment as an exemplary governance instrument to address issues of democratization in STI governance.

This chapter is structured as follows: First, it provides a short history of how participation and societal engagement have developed into core aspects of STI governance (section 2.1) and how they have been conceptually anchored in deliberative democracy (section 2.2). At the risk of ignoring precious lessons, seeing as there is always more than one (hi-)story that matters, this short introduction follows a mainstream narrative about participation and societal engagement, including Responsible Research and Innovation and technology assessment. Finally, section 2.3 addresses unresolved issues and tensions of participation and societal engagement in the current debate. This sets the scene for zooming in on the phenomena of opening up and closing down (Chapter 3).

2.1. Looking back: a short history of participation and societal engagement in science, technology, and innovation governance

After WWII, decision-makers and broader society typically perceived progress in science and technology as societal progress. Science and technology became a favored way to foster prosperity and wealth. An influential landmark for this viewpoint was in 1945, when in his report *Science as the Endless Frontier* US scientific advisor Vannevar Bush argued that modern science and technology are the cornerstones of progress, provided they receive proper governmental funding and provided they are freed from political intervention (Bush 1945). Prevailing through the 1950s and 1960s, this motto gave way to state-run large-scale technological projects, like nuclear power plants and the Space Race between the USA and the Soviet Union. Technology had become an *issue of politics*: the state was in charge to ensure its autonomous development and became a main factor to enable agency for STI. Intellectual debates of the time became increasingly aware of this evolving issue of technocracy. Alerted in this regard, intellectuals criticized the strong role of the state with regard to technology, yet conceptualized their relation in different ways (e.g., Ellul 1964, and later on Gehlen 1980, among others). Together with increasing societal unrest about side effects, such as environmental pollution and the employment of abhorrent technologies in the Vietnam war, the role of STI in society changed: policy and wider society considered it less and less as an autonomous societal field best to be left alone; rather, STI increasingly appeared as an integral part of society. Technology was increasingly perceived as controllable, steerable, and shapeable.

Perceiving technology as *socially shapeable* and in need of intervention shifted how agency was enabled in the context of STI. Increasingly, other actors besides the state involved themselves in STI governance questions. Civil society, activists and social movements engaged in different (research) areas, with academia joining this debate on empowerment. *Civil society* expressed growing concerns about consequences of STI. From the 1970s onwards, the public's acceptance of large-scale technology projects diminished as concerned citizens and environmental organizations challenged experts' risk assessments and evaluations[1]. Eventually, resistance against individual large-scale technology projects evolved into acknowledging environmental side-effects of STI more broadly: examples of such controversies relate to the impact of chlorofluorocarbons on the Earth's ozone layer, or the phenomenon of 'acid rain'. These concerns gained broad political impact as they culminated in the foundation of Green Parties, authorities for environmental protection, or dedicated Ministries and Federal Environmental Agencies in the US and Europe at that time[2]. However, environmental activism was not the only area where civil society got engaged. In medicine as well as in research more broadly, self-help groups, social movements, and non-governmental organizations (NGOs) demonstrated the usefulness of alternative perspectives and additional knowledge and acted as a corrective for expertise. Thus, civil society virulently opened up research processes and enriched research agendas (Irwin 1995, Epstein 1996a, b, Callon and Rabeharisoa 2003, Breyman et al. 2017).

This demand for inclusion entailed long-term structural changes in academia and the political arena by empowering agency in different ways. Social sciences and humanities were increasingly grappling with questions of how to include marginalized societal actors from an analytical point of view. New social movements united intellectual and political movements in opposing untested, risky, or potentially harmful technologies (Breyman et al. 2017, 292). Early Science and Technology Studies (STS) groups joined in criticizing postindustrial society for its rapid changes, post-materialist culture, and extra-parliamentary New Politics of the 1960s and 1970s (Breyman et al. 2017, 290). Particularly, the 'low church' of STS underpinned activists' requests with scientific findings, tying public resistance to academic debates. STS scholars de- and re-constructed innovations to identify, address, and counter inequalities like benefits, costs, and risks of technologies. Eventually, they promoted credos of *socially acceptable* technology development. To this day, these activist interests co-exist together with a diverse set of STS theories, concepts, approaches, perspectives, and methods for analyzing science and technology (Breyman et al. 2017).

Beyond STS, the increasing call for participation and societal engagement shifted how to conceptualize the epistemic basis of science, i.e., the paradigm of knowledge

[1] For an analysis of the conflict about the Austrian nuclear power plant Zwentendorf see e.g., Felt 2015.

[2] For example, the US Environmental protection agency was founded in 1970 (https://www.epa.gov/history/origins-epa [accessed 16 July 2023]), the German Federal Environmental Agency in 1974 (https://www.umweltbundesamt.de/das-uba/geschichte-des-uba-des-umweltschutzes [accessed 16 July 2023]), the Environment Agency Austria in 1985 (https://www.umweltbundesamt.at/en/about-us [accessed 16 July 2023]), the Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection in Germany in 1986 (https://www.bmuv.de/ministerium/chronologie/umweltpolitische-meilensteine-von-1986-bis-heute [accessed 16 July 2023]), etc.

production. The complexity of contemporary societal challenges, like countering climate change or ensuring sustainable development, rendered conventional ways of doing science inappropriate: conventional science would puzzle about questions of detail, but remain unsuitable to tackle real-life questions. To complement this conventional scientific paradigm (i.e., doing science in a disciplinary, specialized way), scholars from the 1990s onwards advocated forms of transdisciplinary, heterogeneous, anti-hierarchical, contextualized, and socially robust knowledge. Mode-2-science (Gibbons et al. 1994, Nowotny, Scott, and Gibbons 2001, for a review on the topic see Hessels and van Lente 2008), post-normal science (Funtowicz and Ravetz 1993) or inter- and transdisciplinary science (Pohl 2008, Pohl and Hirsch Hadorn 2006) all promote new ways of knowledge production, which involve diverse scientific and non-scientific actors to include their perspectives and expertise adequately.

With time, ongoing calls for involving pluralist perspectives also changed how to support decision-making in STI and STI governance and how agency is exerted. Technology assessment is one institution that owes its very existence to political calls for inclusion and has considerably shaped how policy advice in STI governance is conducted. The same can be said for science policy programs like Mission-Oriented Research and Responsible Research and Innovation. They pile on calls for inclusion and explicitly assign it a second, central task: to explicate the *normative* shaping of agency in STI.

Technology assessment (TA) enriched political structures for STI decision-making from the 1970s onwards. Originally, the US Congress tasked the Office of Technology Assessment (OTA, founded in 1972) to provide information on technology independent from the US Government. The OTA offered fact-based information on and assessments of potentially contested technologies over decades before it was eventually shut down in 1995 (Sadowski 2015). Inspired by the work of the OTA, TA was institutionalized all over Europe in the 1980s, to inform political decision-makers and the public about technologies and sociotechnical developments. To do so, TA's forms of institutionalization varied considerably, from Parliamentary units to public research institutes (Nentwich and Fuchs 2021, Ganzevles, van Est, and Nentwich 2014). Also, methods and approaches of conducting TA differ widely. Originally, TA provided expert-based policy advice on specific technologies, but adjusted to different contexts over time (for a cross-European comparison see Ganzevles, van Est, and Nentwich 2014). In particular, it emphasized inclusive technology development and promoted various ways of participation and societal engagement through participatory (Joss and Bellucci 2002), constructive (Schot and Rip 1997) or real-time TA (Guston and Sarewitz 2002). In context of emerging technologies, scholars identified an "interpretative turn" in TA (Bogner and Torgersen 2015), and even "hermeneutic TA" (Grunwald 2014), which highlighted the importance of analyzing narratives and visions for TA. Thus, TA shifted its focus from consequences to design: it emphasized procedural rather than result-based qualities, and pro-active rather than *ex post* evaluations. In short, the history of TA's institutionalization reflects the trend to design technology and innovation more inclusively: starting with the empowerment of the US Congress, TA adapted to varying political and scientific demands for social inclusion. These demands eventually cumulated in the 'participatory turn' in policy of the early 2000s. Looking at the bigger picture, this participatory turn introduced and strengthened a specific model of democracy, i.e., deliberative democracy, through "reconfiguration and remaking of the elements and relations that make up science and democracy" (Chilvers

and Kearnes 2016, 56, see also section 2.2.1). Thus, TA, along with social sciences more broadly, eventually stirred a specific conceptualization of democracy altogether through emphasizing participation and societal engagement in a specific way.

A second example of how agency is shaped in STI governance can be found in *science policy programs*. Concepts like *Mission-Oriented Research* (Mazzucato 2018) and *Responsible Research and Innovation* (von Schomberg 2013, Owen et al. 2013) explicate values and normative aspects of STI. While their significance in terms of dedicated funding schemes has decreased, both concepts still effectively guide science policy, and thus, publicly funded research and innovation. In addition, the increasingly normative approaches to science policy suggest an active and influential role for STS (Delgado, Kjølberg, and Wickson 2011, Bauer, Bogner, and Fuchs 2021).

Mission-Oriented Research (Mazzucato 2018) aims at bridging individual research projects and wider societal objectives, such as the Grand Challenges of the Lund Declaration (2009)[3] and the Sustainable Development Goals of the United Nations[4]. Clear, targeted and time-restricted 'missions' set out to ensure coherence and interlinking of research. To identify and implement societally relevant goals, these missions build on interdisciplinary research and stakeholder involvement and should, overall, ensure a multiplicity of STI pathways (Mazzucato 2018, 15). Yet, these missions do not necessarily involve actors of a wider public, but rather relate to national research strategies of EU Member States and industries (Mazzucato 2018, 16; for the example of a 'plastic free ocean' see Mazzucato 2018, 24-26). This implies a limited (or rather, focused) scope of participation and societal engagement as these missions primarily engage stakeholders from private research, industry, and business (Mazzucato 2018).

Responsible Research and Innovation (RRI) conceptualizes how to conduct science and research and how to develop products in a responsible way. RRI builds on former attempts to strengthen responsible innovation; therefore, I address responsible innovation (RI) and responsible research and innovation (RRI) together as R(R)I for the sake of simplicity (for a distinction of these discourses see Owen and Pansera 2019). R(R)I's roots can be traced to different academic discourses going back to the 1960s at least, if not further (Shanley 2021). However, it has taken its specific shape over the last 10 years (Owen, von Schomberg, and Macnaghten 2021). Generally speaking, R(R)I integrates, combines, and extends established understandings of STI and STI governance. Since the early 2010s R(R)I has coined academic and political debates, especially in the context of emerging technologies, which had fundamentally challenged social sciences discourses and regulatory practices (see for example Åm 2015 for the governance of nanotechnology and nanomaterials). While different interpretations of R(R)I prevail, they show certain communalities such as emphasizing reflexivity, anticipation, responsiveness, and, above all, inclusion of actors (Owen et al. 2013, von Schomberg 2013). On a policy level, the European Commission defined R(R)I more concretely and implemented it as a core feature of the Horizon 2020 (2014-2020) funding program (European Commission 2014). Here, procedural aspects are complemented by normative orientations such as the Grand Challenges of the Lund Declaration of the European Commission (2009)[5], the Sustainable

[3] https://era.gv.at/era/societal-challenges/the-lund-declaration/ (accessed 16 July 2023).
[4] https://sdgs.un.org/goals (accessed 16 July 2023).
[5] https://era.gv.at/era/societal-challenges/the-lund-declaration/ (accessed 16/07/2023).

Development Goals of the United Nations[6], or sustainability in general (Owen, von Schomberg, and Macnaghten 2021). Thus, overall, R(R)I aims at enabling a broader reflection on (emerging) technologies or sociotechnical developments. It exceeds traditional mechanisms of technology appraisal such as risk assessment and emphasizes the malleability of STI along the way. Moreover, it assigns a different role to the broader public than Mission-Oriented Research. In R(R)I, both participation of stakeholders and the public is supposed to ensure inclusion and social robustness of decision-making (for a review on societal enagement see Bauer, Bogner, and Fuchs 2021).

This short historic overview presented the coming about of today's understanding of how participation and societal engagement should be conducted in STI governance. Against the background of complexity, epistemic shifts in knowledge production, together with an increasing interest of a broader range of actors to get involved, affected the role of inclusion in STI governance. Including new actors and analyzing the processes and impacts of doing so have been central for social sciences in the context of STI and STI governance for decades. Thus, my interest in how dialogue, and, by extension, agency, are constituted in the context of emerging technologies lies at the very core of STS.

In particular, I presented two mechanisms of STI governance which emphasize inclusion. The first one, technology assessment, aims at supporting decision-making and has been committed to foster various ways of inclusion from its early days. It has explored the role of different knowledge bases for policy processes, including participatory knowledge, narratives, and visions. The second one concerns the shaping of STI in a more direct way: science policy programs like Mission-Oriented Research or R(R)I explicate the normative assumptions of STI and guide these activities in a specific direction. My thesis relates to both of these STI governance mechanisms since my empirical work is conducted in the context of technology assessment with the framework of R(R)I guiding my case studies explicitly or implicitly (Chapter 5-7). R(R)I in particular promotes opening up by encouraging comprehensive rethinking of STI and STI governance, and engages with closing down to reconsider how agency can be enabled or constrained. Therefore, activities conducted in relation to R(R)I provide a suitable starting point for my research.

2.2. Contextualizing participation and societal engagement in theory

To anchor the debate of current STI policies, it is helpful to look at how the aims of participation and societal engagement in STI relate to specific models of democracy (section 2.2.1), and how these aims address questions of expertise (section 2.2.2). In this section, I will present an overview on each of these well-researched aspects, but do not attempt to provide an in-depths analysis of these issues. Instead, the purpose of this section is to set the scene for the subsequent discussion of practical tensions (section 2.3) and the study of opening up and closing down (Chapter 3).

2.2.1. Deliberative democracy: specifications from democracy theory

Political theory has addressed participation and societal engagement extensively as to their role within and their effects on democratic systems. While I do not claim to cover this debate in detail, I find it helpful to briefly contextualize participation and societal engagement to indicate their extensive and fundamental societal impact, beyond the specific topic they address (i.e., technology). During the *participatory turn* in the early

[6] https://sdgs.un.org/goals (accessed 16/07/2023).

2000s, participation and societal engagement became extremely popular, relentlessly promoted by (social) scientists, TA practitioners, and actors of STI governance (Braun and Schultz 2010, Chilvers and Kearnes 2016). In principle, emphasizing participation and societal engagement in STI consolidates changes in knowledge production and in constructing legitimacy in STI. At the same time, participation and societal engagement constitute specific practices of democracy which, again, generate political authority in a certain way (Voß and Amelung 2016, 763). Thus, they strengthen a specific model of democracy, i.e., deliberative democracy, and by so doing, affect the democratic order altogether.

Overall, deliberative democracy is but one model of democracy and is often contrasted against other democratic models, such as representative democracy. Both models are concerned with questions of politics, i.e., of legitimate participation in decision-making. However, each model defines whether and in what form political participation is considered legitimate in a different way. Ideas of participation and public deliberation are rooted in *democratic deliberative theory* (Delli Carpini, Lomax Cook, and Jacobs 2004). Democratic deliberative theory rejects individualistic or economic understandings of democracy and emphasizes increased accountability and discussion: „[d]eliberative democracy focuses on communicative processes of opinion and will formation that precede voting" (Delli Carpini, Lomax Cook, and Jacobs 2004, 317). As deliberative democracy assumes that a legitimate political order can be justified, democracy shifts from vote-centric to talk-centric (Chambers 2003, Delli Carpini, Lomax Cook, and Jacobs 2004). Deliberative democracy criticizes ideas of representative (or 'aggregative') democracy for their implicit normative premises, like the assumed preferences of actors, and promises a higher legitimacy of decision-making than majority decisions (Saretzki 2014). In turn, deliberative models of democracy are criticized for their lack of knowledge of how preferences are generated; in addition, their legitimacy is debated (Saretzki 2014). To mediate these shortcomings on both ends, deliberative democracy is usually supposed to expand rather than substitute representative democratic practices (Saretzki 2012, 2014).

Consequently, the role of participation in (STI) governance is still being debated (Mansbridge et al. 2012, van Oudheusden 2014, Voß and Amelung 2016). The relation between deliberation and the wider political system remains challenging due to their different rationales (Bora 2006, van Oudheusden 2014). Accordingly, scholars have proposed procedures that separate participatory phases from political decision-making to ensure distinct, but mutually responsive procedures (Bora 2006). In particular, the idea of opening up and closing down at the core of my thesis relates to this very separation. By adopting the *idea of phases* of deliberation and political decision-making, Andy Stirling distinguishes between technology appraisal, i.e., information, and technology commitment, i.e., the formation of technology policy. However, he is well aware that in STI governance incumbent interests may pervade both (Stirling 2008). Until today, these tensions between practices of deliberative and representative democracy remain unresolved.

2.2.2. Expertise in deliberative democracy

To assign specific purposes to phases of STI governance implies a distinction between deliberation and decision-making and likewise, between scientific and political phases. In so doing it addresses the question of the role of expertise within deliberative democracy. For my thesis, both the theoretical as well as the practical implications of this question of

expertise are relevant. In this section, I will sketch out the theoretical challenges, while practical implications will be discussed in my empirical chapters (Chapters 5-7).

As outlined above, deliberative democracy aims for rationally grounding decisions and fosters inclusion through participation and societal engagement. The participatory turn in particular aimed at enhancing the accountability and credibility of results through interactive knowledge-making (Jasanoff 2003, in Braun and Schultz 2010, 403). By so doing, it supported the move from an 'elitist expert model' towards a model of transdisciplinary and participatory policy-making (Braun and Schultz 2010). Behind these efforts lurks the question of how to conceptualize expertise, as a specific condition for participation and societal engagement. Who is equipped to contribute to STI decisions, and in what way? And, as a follow up: which knowledge or decision-making capacity can legitimately be assigned to whom in a democratic system?

These questions evoke *tensions between policy and science*, i.e., between the right to participate and the knowledgeability necessary for the task – and thus, define how agency is enacted in STI governance. In principle, concepts of deliberative democracy are rooted in ideas of Jürgen Habermas, who contrasts elitist governance structures and democratization (Roberts et al. 2020, 5). As part of the former, scientific experts are key resources in governance (Moore 2017b, Roberts et al. 2020). Here, expertise fulfills a specific function by assigning specialized knowledge and interpretation to experts, but holds theoretical challenges in the light of deliberative democracy (Berg and Lidskog 2018, Durant 2015, Moore 2017b, Roberts et al. 2020). This is because expertise enforces a division of labor between science and policy and limits the role of citizens in decision-making (Moore 2017b, 43, see also Christiano 2012, Roberts et al. 2020). This tension between policy and scientific expertise remains unresolved, in particular as it shifts over time. Terms like 'politicization of expertise' and 'scientification of politics' describe opposite tendencies of these societal realms to dominate one another (Moore 2017b, cf. Weingart 1999).

To address the democratic ambiguity of expertise and to mobilize it for my empirical work later on, I largely follow Alfred Moore (2017b). He states that, in general, expertise is characterized by specific qualities, such as status, credibility, reliability, and neutrality. In STI governance, these qualities are under pressure as "[e]xpertise becomes political to the extent that it is a site of conflict under the shadow of coercive decision" (Moore 2017b, 36). When expertise becomes contested in the light of decision-making, two contrary 'anxieties' rise in relation to deliberative democracy: first, that a democratic debate is narrowed down through 'technocratic' politics; second, that expertise, if politicized, erodes and appears arbitrary (Moore 2017b). Simply put, the two anxieties relate to a technocratization of policy and to a politization of science, respectively.

The first anxiety is based on the understanding that social problems are best managed by intelligent expert action (Moore 2017b). This understanding draws from a "linear model of expertise" (Durant 2015) and produces "a politics that […] [narrows] the scope for citizen involvement and for reason in politics" (Moore 2017b, 38). It is based on Habermas' understanding of technocracy, which assumes that specialist knowledge constricts the scope of political choice but at the same time emphasizes that irreconcilable value pluralism cannot be rationally grounded. Yet, Moore argues that expertise does not necessarily cumulate into technocratic politics. Instead, this depends on the respective rhetorical mode: technocratic politics consists of a specific rhetorical mode, which is

defined by "the use of a technically grounded language of necessity in an attempt to avoid explicit debate and justification of value positions" (Moore 2017b, 39).

Thus, this first anxiety relates to experts in political decision structures: here, the *information asymmetry* between experts and lay people potentially deprives the latter, for example decision-makers, of control. Expert discourse is suspected to limit public and political deliberation. As Moore puts it, expert authority defines "what is sayable and unsayable in a particular domain. The worry here is that expert authority has such performative strength that it marks out the channels within which meaningful claims can be raised, and silences those claims that fall outside" (Moore 2017b, 40). In short, expertise endangers democracy by dominating (or 'framing') discourse, a perspective widely accepted in STS (e.g., through notions of co-production, Jasanoff 2004, see also Berg and Lidskog 2018). Settling what counts as science and conducting boundary work reinforces the cultural authority of science (Moore 2017b, 41). Yet, Moore concludes that it is not the privileged status of expert knowledge in a decision process that challenges democracy; rather, it is granting *political* weight to expert authority. This happens when political struggles are conducted on the terrain of claims to expertise instead of societal values. Instead of fighting over societal values, these contestations become rationalized, and, thus, hidden. Thus, the first anxiety regarding expertise in deliberative democracy is therefore to displace political struggles into the domain of expert claims (Moore 2017b, 41-42).

The second anxiety relates to considering *expertise as an enlightenment of political will* to support democratic goods. Here, expertise informs public and political deliberation, empowers democratic collective action, and tells truth to power from a position of independence. To meet demands for a factual basis, experts provide lay people like politicians and citizens with filtered theories defined in expert deliberation (Christiano 2012). These theories constrain options according to basic expert consensus (Moore 2017b, 43). This expert consensus ensures that options are epistemically reliable, publicly accessible, and rely on reciprocity of information (Moore 2017b, 44, see also Gutmann and Thompson 2004). Consequently, expert consensus constitutes a precondition for public reason. Transferring competences to experts in public deliberation appears appropriate; in turn, rejecting such a transfer equals a rejection of a reasonable discussion and violates terms of reciprocity. This implies that a division of labor, between questions of collective goals and values and matters for experts, strengthens democratic collective action (see e.g., Collins and Evans 2007). On the other side, a potential erosion of epistemic authority threatens the democratic ideal of collective action empowered by expertise.

In any case, reality falls short of this ideal: a clear division of labor hardly exists since experts are most valuable in decision-making when they not only state facts but also advance interpretations (Moore 2017b, 46). 'Telling truth to power', i.e., advising policy from an independent position, is only possible if the "self-regulating capacities as an autonomous professional community" of experts become effective; yet, they bear the risk of developing into fraternal lodges (Moore 2017b, 47). Hence, to establish or preserve independence of expertise is crucial, but challenging.

Moore argues that politicizing expertise is particularly alarming because reasonable arguments potentially become marginalized (Moore 2017b, 44). Moreover, it threatens the standing of expertise itself as the "erosion of expert authority seems also to undermine democratic capacities for collective action and informed collective judgement

and deliberation" (Moore 2017b, 48). Thus, this second anxiety relates to the erosion of expertise as a sign for a degrading democratic system more generally.

Overall, the question regarding the role of expertise in deliberative democracy is still contested. Nonetheless, scholars have proposed ways to move forward: for example, Moore's *critical elitism* recognizes that questions of expert authority need to be settled in relation to political issues, even if only provisional. These settlements need to remain "open to forms of public scrutiny and to demands for communicative accountability"; moreover, they need to recognize discarded interests and arguments (Moore 2017a, 179, also reflected in Roberts et al. 2020). On a more practical level, Stirling's approach of opening up and closing down also provides a starting point to tackle the challenge of reconciling expertise and participation, i.e., analytical and participatory knowledge, against the backdrop of deliberative democracy (see Chapter 3).

2.3. Practical challenges for participation and societal engagement

Participation and societal engagement do not only face theoretical challenges with regard to their rooting in democratic theory, or their relation to questions of expertise. Despite decade-long research, there are still challenges remaining on an empirical level as well. As questions of agency in STI are shaped by the form that participation and societal engagement take and the structures they rely upon, I will dive into these issues. Yet, before addressing some of them in detail, I briefly draw my readers' attention to two meta-aspects in relation to participation and societal engagement: the question of their impact, as well as their performativity. Both aspects widen the perspective on participation from individual practices to wider political and cultural contexts. I do so to illustrate that while well-established, the actual effects of participation and societal engagement remain somewhat vague.

Participation and societal engagement are *interventions*. They aim at creating an effect in the respective system or procedure that they are implemented in. Yet, despite their popularity, defining their *impact* or even impact criteria remains controversial. With regard to science, inclusion affects the quality criteria, evaluation, and legitimacy of research: social accountability complements peer-review in defining legitimacy and relevance of research. Moreover, STS emphasizes the performative quality of participation and societal engagement: since they are enacted anew each time, they are highly context-specific (e.g., Felt et al. 2009). This interferes "with a contemporary need in practice for transferrable models that can allow for comparisons and a standardisation in quality control measures" (Delgado, Kjølberg, and Wickson 2011, 836). Consequently, studies of impact usually remain dependent on criteria defined for each individual case (Delgado, Kjølberg, and Wickson 2011). Moreover, the relation between participation and societal engagement and their effects remains contested. For example, Hansen and Allandottir (2011) found that participatory TA in the field of nanotechnology hardly affected policy outcomes. Rather than constituting conditions for explaining policy outcomes, the outcomes provided arguments to legitimize the participatory procedures (Hansen and Allandottir 2011). Thus, impacts of participatory procedures seem difficult to prove empirically. However, scholars attribute emancipatory effects for society to some participatory formats (e.g., mini-publics, see Ryan and Smith 2014). They argue that these effects are based on the assumption that such formats convey forms of reasoning to a wider public irrespective of their concrete outcome (Niemeyer 2011).

Other scholars have emphasized the *performative* qualities of participation and societal engagement. For example, Voß and Amelung (2016) considered participation and societal engagement as ontological politics: specific participatory methods combined with a "specific topology of governance" create a "trans-local space of governance knowledge" (Voß and Amelung 2016, 763). The results are far-reaching, as *"the ordering and expansion of this particular space [trans-local space of governance knowledge, may be considered] as a process of cultivating a particular imaginary of democracy (Ezrahi 2012), and thus as an informal process of constitutional reform on a transnational scale"* (Voß and Amelung 2016, 763). Hence, the very practices of participation and societal engagement eventually affect the constitution of wider political conditions (see also section 2.2.1). Increasingly, social sciences have required to analyze not only individual participatory practices, but to link these practices to their respective conditions. They called for investigating "the spaces of standardization that form around technologies and expertise of participation; [and] interrelating ecologies of participation that make up spaces of negotiation" to see how they perform and relate "to wider political cultures and constitutional relations between citizens, science and the state" (Chilvers and Kearnes 2016, 56). Thus, to better grasp their impacts, social sciences increasingly focus on systemic approaches in analyzing participation and societal engagement (e.g., deliberative systems, see Mansbridge et al. 2012).

My own work on opening up and closing down cannot claim to do justice to a systemic investigation of "ecologies of participation" (Chilvers and Kearnes 2016). Yet, the decision to analyze a diverse range of settings of participation and societal engagement with regard to different emerging technologies aspires to exceed isolated approaches to inclusion. To use the words of Sykes and Macnaghten (2013), I set out to "move beyond thinking of public engagement in isolation, to talk about *governance in the public interest*" (Sykes and Macnaghten 2013, 104, emphasis in original). Thus, I start from the assumption that participation and societal engagement constitute one instrument to organize public space, i.e., to ensure inclusion in STI governance and show potential for opening up. Yet, the discussion on the design, purpose, form, and function of participation and societal engagement is ongoing. Supposedly, even if difficult to prove systematically, a range of aspects affect impact, including *"different motivations for doing it [participation and societal engagement, author's note], the timing of dialogues, the way they are run, and the involvement and responses of the policy-makers"* (Sykes and Macnaghten 2013, 97).

As a starting point to look at opening up and closing down, I will outline some unresolved challenges for participatory practices as described in the literature. They relate to the theoretical questions I indicated above. The question of how to integrate deliberative settings within other models of democracy defines purpose and scope, timing and organizational form of participation and societal engagement; the question of how to deal with asymmetric constellations of information and power addresses the construction of actor roles as well as the framing in and of processes. Thus, in participation and societal engagement, purpose and scope, timing and organizational form, the construction of actor roles, and framing each reveal specific assumptions and challenges shaping the potential for agency in practice. In the following sections, I will shortly outline the discussion on each of them to illustrate where I hope to contribute on a practical level.

2.3.1. Purpose and scope of participation and societal engagement

Defining purpose and scope of participation and societal engagement are crucial in how they *tie to existing structures* and practices of STI governance: they justify participation and societal engagement and eventually specify how impact in STI governance is generated. Moreover, they define how agency can unfold in engagement practices on a basic level.

The *purpose* of participation and societal engagement in particular has been carefully reflected and critically reviewed to fulfill specific functions in (STI) governance (e.g., Rossignol, Delvenne, and Turcanu 2015). In context of decision-making, scholars identified three basic *rationales*: substantive, normative, and instrumental (Fiorino 1990, also see e.g., Stirling 2008, Delgado, Kjølberg, and Wickson 2011). The substantive rationale aims at improving sound decision-making through including lay judgements, which are considered more sensitive to political and societal values than expert models. The normative rationale emphasizes the democratic ideal behind including lay judgements; and the instrumental rationale uses lay participation to legitimatize decisions. The latter indicates a potential mismatch between rationales of policy and of participation and social engagement, turning the latter into pragmatic tools if not properly prioritized (Nielsen Porsborg, Lassen, and Sandøe 2011). In this case, they foremost ensure public acceptance of predefined perspectives or actions (see e.g., Degelsegger and Torgersen 2011, for the Austrian administration, or Marris 2015, for the field of synthetic biology). The three rationales differ considerably in scope and affect how agency is enabled or constrained in different ways. Accordingly, in the light of opening up and closing down, their integration in participation and societal engagement needs to be carefully reflected.

Overall, TA and STS consider participation and societal engagement as a *means to empower* citizens and stakeholders in STI governance (Stirling 2008). Highlighting the empowerment of citizens implies that STI governance modulates rather than controls sociotechnical developments (Parotte and Delvenne 2015, 989). How to achieve such empowerment is flexible and relies on the function of the respective activity. Functions range from evaluating policies (e.g., in consensus conferences, see Grundahl 1995, among others) to advising and supporting technology development (Schot and Rip 1997, Joss and Bellucci 2002, von Schomberg 2013, Owen et al. 2013) to co-creation (Voorberg, Bekkers, and Tummers 2015) in terms of user innovation (von Hippel 2005) or citizen science (e.g., Strasser et al. 2019). Each of these approaches provides different opportunities to shape STI, i.e., to enable or constrain agency. To avoid their instrumentalization, transparency of these processes is crucial (Stirling 2006, 2008).

The very purpose of participation and societal engagement affects the *scope* of their activities: they can shape STI, i.e., sociotechnical developments themselves, as well as STI governance, i.e., technology policy. For my work, both perspectives are valuable for exploring how agency is confined. Regarding actors' agency, a core characteristic that shifts between these two is the extent to which participants are able to challenge basic assumptions. This differs considerably between STI and STI governance. Usually, the former provides only restricted leeway for questioning basic assumptions, once the technological pathway is decided. In contrast, in STI governance, moving from technology-centered towards problem-centered or challenge-based questions shifts the focus of the debate, i.e., opens up the scope, considerably. Discussing how to best counter world hunger instead of 'green biotechnology' gives way to a whole range of (afore unconsidered)

potential solutions, including non-technical ones. On a policy level, the Lund Declaration of the European Commission from 2009[7] has declared the Grand Challenges as central for structuring research and funding activities. By so doing, it has opened up and broadened the debate on sociotechnical futures beyond purely technical approaches. In practice, however, participation and societal engagement activities frequently remain framed by specific technologies. This indicates a tension between technology commitment versus appraisal, a core matter for Stirling (2008). Moreover, it implicitly raises the question of incumbent power structures and knowledge hegemony that become mirrored in practices of participation and societal engagement (see Chapter 3).

Thus, the question of purpose and scope of participation and societal engagement defines their function for STI and STI governance. Accordingly, my empirical case studies revolve around the tensions between contributing to STI, e.g., generating knowledge, and STI appraisal, e.g., furthering STI governance, and how the assumptions of each confine agency. The scope of the former usually remains more closed down, whereas the latter allows a more fundamental opening up of the debate, i.e., to challenge assumptions and ordering systems. Consequently, when looking at opening up and closing down, scrutinizing the function and rationales of participation and societal engagement is fundamental as reconstructing their purpose and scope means reconstructing perceived shortcomings in STI governance altogether. This, again, immediately relates to opening up and closing down, by exploring different framings (see section 2.3.4).

2.3.2. Timing and organizational form

Like purpose and scope, timing and organizational form tie participation and societal engagement to existing governance structures and facilitate how agency is enabled in empirical contexts. In particular, timing is crucial as it pre-structures the very understanding of participation and societal engagement in STI and STI governance.

Timing affects the malleability of STI, including the scope of participation and societal engagement. In the widely-cited 'Collingridge dilemma', Collingridge (1980) addresses the challenge of *timing interventions* in STI in a nutshell: the earlier the intervention, the more malleable the technology, yet the less impact is to be expected. The later, the more concrete the technology (or issue) at stake; thus, changing the technology pathway becomes increasingly difficult due to decisions and investments made (Collingridge 1980). In relation to participation and societal engagement, Jellema and Mulder (2016) found that the effectiveness of participatory tools and methods depends on the timing and level of involvement in STI (Jellema and Mulder 2016). This emphasizes that participation and societal engagement are context-specific; they bind together aspects of usefulness to address a specific issue, organizational form, and expected impacts of activities. Altogether, these aspects define the potential scope of debate. Hence, timing affects how (easily) debates are opened up or closed down.

Collingridge, like many other scholars, constructs STI as a *linear* endeavor. STI governance usually follows such an understanding and conceptualizes science-society relations in a linear and unidirectional way (Wynne 2006). In this context, participation and societal engagement increasingly moved "upstream" to ensure impact of debates as long as technologies are still malleable (Wilsdon and Willis 2004). Accordingly, upstream dialogue may *"help define the matters of concern at a time when this can be integrated*

[7] https://era.gv.at/era/societal-challenges/the-lund-declaration/ (accessed 16 July 2023).

back into the R&D [research & development, author's note] innovation process" (Sykes and Macnaghten 2013, 98). In context of emerging technologies, participants of engagement activities elaborate on issues early-on in the innovation stream to steer subsequent activities in a desirable and socially robust way – in short, upstream engagement is characterized by the exploration of issues, pathways and alternative solutions. In contrast, engagement further downstream is more and more bound to prior decisions. As Sykes and Macnaghten (2013) summarize: *"the contours of the debate are known, and established positions may already be set out […] [as participation and societal engagement] tend to be tied closely to specific policy goals and outcomes, on domains of science and technology which are relatively developed, and which are known already to pose social and ethical problems and dilemmas"* (Sykes and Macnaghten 2013, 97).

Recently, STS scholars have called for a *dynamic and complex* depiction of innovation (and STI in general) since the understanding of irreversible and simple technology trajectories contradicts ideas of co-production, changeability, and context dependency (Delgado, Kjølberg, and Wickson 2011). Moreover, regarding public engagement, it has been shown that the relation between 'upstream' and 'downstream' engagement is anything but linear: upstream engagement hardly prepares for or impedes contestation further downstream (Felt and Fochler 2010). This is especially important since debates may not even exist 'upstream' in the first place, e.g., in the case of spontaneous inventions or unpredicted side-effects (von Schomberg 2013, von Schomberg and Blok 2019). Thus, in participation and societal engagement the relations between upstream and downstream need to be constructed anew every time: *"even though an upstream setting may offer more possibilities to discuss basic value questions, in order to do so the relation between the upstream design and the participants' imaginations of science and the innovation process has to be addressed"* (Felt et al. 2009, 368).

These more recent understandings of STI indicate that common ideas of innovation imply a linear understanding of innovation and suggest that these ideas need to be opened up themselves. However, large parts of literature still address participation and societal engagement in context of a linear understanding of STI, as the well-established use of the *metaphor of the innovation stream* shows. In academic as well as policy literature, this metaphor (and related concepts like 'upstream engagement'), features prominently and structures the debate about the timing of participation and societal engagement (Bauer, Bogner, and Fuchs 2021). Metaphors like upstream, mid-stream and downstream innovation impose a specific and largely oversimplified perspective: STI hardly follow a predetermined course. Instead of adhering to the linear concept that underlies the Collingridge dilemma, innovation may occur spontaneously, dismissing linear models of product development from basic research to marketing altogether (von Schomberg 2013, von Schomberg and Blok 2019). Also, innovation may occur in a bidirectional manner with principles of feasibility and marketability affecting basic research (as mirrored in the term 'technoscience', e.g., Bogner and Torgersen 2015).

Constructing STI as a *linear endeavor* has important implications for my work. Opening up and closing down are difficult to address empirically without considering temporal dynamics. Yet, while I am interested in how timing structures my case studies, my main interest does not primarily lie in a macro-perspective on the dynamics of innovation. Rather, I am interested in how agency is enabled or constrained with regard to STI. To do so, following established timing-related narrative figures, such as 'upstream'

engagement may facilitate giving an overall indication of dynamics with regard to participation and societal engagement. Therefore, I (rhetorically) transfer linear understandings of STI to interventions like participation and societal engagement in my empirical work (Chapter 5-7). However, I am aware of the dynamic interrelations that these interventions may face.

In this linear understanding of STI, the *organizational form* of participation and societal engagement is tightly intertwined with timing. Timing allows to address sociotechnical change, to conceptualize *when* stakeholders and the public are affected, as well as changing formats of participation and societal engagement. As I tie together my thesis following a linear understanding of STI for reasons of simplicity only, I will be able to look at 'different points in time' in STI. How participation and societal engagement are initiated and how concerned groups become involved then define the organizational form: top-down or bottom-up, in an invited or uninvited way (e.g., Callon and Rabeharisoa 2008). Thus, timing indicates how procedures need to be organized in order to fulfill a specific function within STI governance settings.

Uninvited participation emerges on its own (Wynne 2007). These activities are not sponsored by government, and societal actors engage out of self-interest in specific topics, including forms of activism and protest (Sykes and Macnaghten 2013). Usually, uninvited participation challenges normative commitments and provides alternative framings of the activity in question, yet often remains neglected in STI governance. It tends "to be dismissed and denied by science and policy institutions as either irrational and/or irresponsible and/or counter-productive to good governance"; at the same time, scholars have highlighted its "potential for institutional reflexivity" (Sykes and Macnaghten 2013, 99). As such, they considered social movements as one form of uninvited engagement to actively and autonomously contribute to a pluralistic society:

> *„Social movements usually have a defined agenda for their engagement, and therefore might be seen to be operating from an instrumental rationale. However, uninvited PP/PE [public participation/public engagement, author's note] may also be seen as an expression of a normative ideal of democracy, particularly in the sense that it is based on a more direct form of democracy (i.e. self-organising citizens)"* (Delgado, Kjølberg, and Wickson 2011, 834).

In principle, STI governance gains from pursuing a broad variety of formats (as I will show in Chapter 6). However, R(R)I especially emphasizes a particular form to generate input for decision-making (Bauer, Bogner, and Fuchs 2021), so-called *invited engagement* (Wynne 2007). These multi-actor dialogues bear the advantages of being plannable, organized in a top-down manner, with professional organizers defining their set-up and framing (Bogner 2012b, Bogner and Torgersen 2015, Delgado, Kjølberg, and Wickson 2011). These qualities allow to initiate invited engagement early-on ("upstream") even if public interest is still low; consequently, dynamics of invited participation and societal engagement do not correlate with public concerns, but evolve independently (Burgess 2014). This strong emphasis on plannability and controllability effectively alter the role of participation and societal engagement in STI governance compared to uninvited engagement. Braun and Schultz (2010) argued that participation and societal engagement have 'outlived' technology conflicts like the debate on genetically modified organisms (GMOs) by shifting control over constructing the objects of debate from the public to

governments and organizers (Braun and Schultz 2010, see also Bogner 2012b). As a result, the strong influence of organizers designs harmonious win-win situations, where – in principle – everyone can benefit. However, this implies the cost of more conflictual or antagonistic constellations, and, as a result, entails a hierarchy of publics. Stakeholders based on conflict and struggle like civil society organizations rank below other forms of publics, like lay publics, which more easily align with ideas of consensus and education. As a result, lay publics are considered to hold a higher moral authority compared to stakeholders like civil society organizations (Braun and Schultz 2010). At a micro-level, social dynamics reconstruct such win-win situations by minimizing the threat of disturbing the overall social setting, i.e., through 'mutual taming' of actors (Felt et al. 2009).

In my thesis, I will investigate both forms of organization, invited as well as uninvited engagement, although the latter will be largely underrepresented. I will explore their respective potentials with regard to STI governance, and especially R(R)I. Normalizing both organizational forms in STI governance implies a shift in power constellations, away from organizers towards a broader range of actors. This shift ties into the legitimacy of speech and perspectives, and thus, relates to questions of opening up and closing down, i.e., how agency can be enabled or constrained. Consequently, organizational forms are crucial for better understanding opening up and closing down.

2.3.3. Construction of actor roles

Besides the question of how to integrate deliberative settings within other models of democracy, deliberative democracy holds challenges with regard to the question of expertise (section 2.2.2). This question pervades the very core of participation and societal engagement, and thus all of my empirical work. It translates to the construction of (asymmetric) knowledgeability in individual engagement settings and evokes further questions of who should have a say under which conditions. As this immediately ties to questions of enabling and constraining agency, i.e., opening up and closing down, I will shortly outline how the construction of experts and stakeholders, as well as the (lay) public, is portrayed in STS literature to raise awareness for the dynamics of these issues in my case studies later on (Chapter 5-7).

In general, the role that actors take within STI governance sets the shape of how they are able to enact their agency and affect STI governance structures. STS studies have elaborated thoroughly on the *construction of actor roles*. Instead of simply being assigned, actor roles "emerge in interactions as a negotiated set of rights and obligations" (van Lente, Boon, and Klerkx 2020, 485). This implies that role construction is increasingly understood as an *active and dynamic* process: actors need to be involved, at least to accept, if not define, their role. This is crucial since all concepts of (public) actors impose "a hugely problematic unacknowledged normative commitment as to the subject-identities of […] publics" (Wynne 2007, 100). Therefore, who is considered part of which actor group in which setting needs careful reflection. Most notably, constructing actor roles does not only concern the lay public but affects public and experts alike as it relates one to another. Looking at the micro-level of participation and societal engagement, the construction of actor roles defines how speaking positions are made available in engagement events, or not (e.g., Delgado, Kjølberg, and Wickson 2011, Braun and Schultz 2010, Felt et al. 2009, Evans and Plows 2007). Thus, it is crucial, whether actors are constructed as lay public or experts. STS has especially focused on how expertise and lay publics are constructed in

invited engagement (see section 2.3.2) as these activities are often initiated by public authorities: they shed light on who is imagined to engage, as well as the roles assigned to actors in wider governance (cf. for example 'scientific citizenship', Irwin 1995, 2001, 2006).

Experts are usually characterized by a specific set of technical or scientific knowledge and skills. Moreover, in deliberation procedures, they are supposed to ensure transparent argumentation, to remain open to different and potentially conflicting claims, and to admit to coherence and truthfulness, all due to their deliberative qualities of reason-giving and consistency (Berg and Lidskog 2018). However, these qualities often imply that experts are imagined to confine to a specific community like science. Recently, this imagination has been challenged: some authors argue for constructing expertise along social immersion and domains of practices, while others call for a "heterogeneous conception of expertise that would recognize the presence of substantial technical knowledge outside the scientific community" (Evans and Plows 2007, 835). Therefore, what counts as expertise in the respective setting needs to be defined individually for each process. Irrespective of the definition, the very role of experts in deliberation needs to be managed carefully. Experts can (legitimately) claim authority on a factual basis (in their area of expertise). However, this authority needs to be reflected when they appear as a stakeholder (group) in deliberation processes to avoid power imbalances: *"the role of experts and organized interests in the deliberative process must consider the extent to which they have well defined interests, and therefore are stakeholders who need to be understood but explicitly managed to avoid disproportionate influence through overextension of their technical or political interests over participants"* (Burgess 2014, 49). Hence, it is particularly important to acknowledge (and deal with) the own interests of actor groups, in particular if their perspectives can easily be objectivized.

Like experts, *the public* has been constructed in different ways, often with a tendency to de-rationalize them. For example, Braun and Schultz (2010) identify a "tendency towards individualised, 'naïve' or 'authentic' subject construction" in state-sponsored engagement activities. This has fundamental implications on a procedural level: participants constructed in this way can hardly challenge such presumptions. As a result, this "implies a tendency to fragment, ethicise, and depoliticise the issue at stake and to foreclose more antagonistic political contestation" (Braun and Schultz 2010, 416). In such a way, participation and societal engagement risk to undermine political contestation. R(R)I has been accused of strengthening this tendency as bottom-up initiatives remain underrepresented under its header (Bauer, Bogner, and Fuchs 2021). In addition, constructing actors in this way may obstruct more facetted descriptions of the relations between publics, states, and industry (Braun and Schultz 2010). Others have identified more varied accounts of the public in participation and societal engagement. Wickson, Delgado, and Kjolberg (2010) define 'laity' in need of education and information, 'consumers' to achieve acceptance of products, and 'stakeholders' to deliberate on socially transformative potential and risks that need to be managed to minimize harm. In addition, they propose a 'public-as-citizens' to express concerns beyond what is possible within these roles, with assigned (ethical) rights and duties (Wickson, Delgado, and Kjolberg 2010, 757).

Moreover, STS has increasingly emphasized the dynamics of *emerging publics*. Conventionally, scholars perceived publics as existing independently from participatory and engagement activities which only needed to be invited to the right procedures to shape

STI (governance). More recently, however, scholars increasingly conceptualized the public as a situational and emerging phenomenon with publics forming based on their interest in an issue at stake (Marres 2007, in recourse to Dewey). This paints a more flexible and heterogeneous picture of 'the public', i.e., emerging specific to controversies. Scholars have used the concept of emerging publics to address an important practical issue of participation and societal engagement, namely engagement fatigue. The concept of emerging publics should counter engagement fatigue by waiting for immediate public concern or interest to arise by itself, rather than constructing it in participation and societal engagement activities from outside (Delgado, Kjølberg, and Wickson 2011). Next to an individualized public, *collective conceptualizations* of the public have enriched STI governance debates. STS scholars have called for including uninvited and organized publics like civil society organizations more prevalently (Hess 2015). Their involvement *per se* remains conditional (i.e., on affectedness of these groups) and thus, bears its own challenges for invited engagement. Foremost, it requires an *a priori* definition of who is affected and should have a rightful say in a specific topic. Moreover, these actor groups tend to be constructed as representatives of a wider community, contributing a specific perspective (Ahrweiler et al. 2019, Ångman 2013, Saarikoski, Mustajoki, and Marttunen 2013). For example, policy actors imagined civil society organizations (CSOs) as a 'societal corrective' in research projects, while they more often provided additional knowledge or access to networks. Thus, rather than taking on a normative role of representing the public, as R(R)I often assumes, CSOs contribute to the epistemic bases of debates or processes (Ahrweiler et al. 2019).

As outlined, STS has constructed actor roles to be more and more flexible. Conceiving actor roles as situational draws attention to the dynamic of opening up and closing down. Yet, for investigating opening up and closing down, not only the roles themselves, but the very process of *separating between different actor groups* from within, i.e., boundary work, needs to be scrutinized. This issue of boundary work reveals conceptual as well as practical particularities. For one thing, some boundaries, like the boundary between science and society are constantly reconstructed by scientific and extra-scientific actors alike, as Felt et al. (2013) argued for the context of knowledge production. Another example are policy's imaginaries of the public. Here, underlying imaginaries of the public deficit model constantly reinforce the impression of public resistance to policies, instead of acknowledging the empowerment of the public. This ignores the capacity of uninvited publics to articulate widespread social and political concerns that reach beyond institutionally defined issues of risk (Welsh and Wynne 2013, 561). Thus, separating scientific experts from the public has been considered unproductive (Sykes and Macnaghten 2013, 101). This indicates that the relation between science and society are in flux, and their relation needs to be conceptualized in a more dynamic way as well. To do so, some scholars have proposed hybrid spaces to reconfigure science-public relationships (Callon, Lascoumes, and Barthe 2011).

In policy contexts, (assumed) boundaries between actors ensure the practicability of decision-making; yet these boundaries too are *susceptible to change*. For example, instead of opposing scientists and publics in STI governance, Delgado, Kjølberg, and Wickson (2011) propose to distinguish experts from non-experts and expertise from democratic processes. This is supposed to hit two birds with one stone. On one hand, it recognizes the importance of institutional practices involving experts in answering

political or moral questions. On the other, it acknowledges that the diversity of expert debates needs the decision capabilities of non-experts. Nonetheless, STS has pointed out that while political (non-expert) and technical (expert) phases each fulfill specific functions in governance procedures, thinking about them as completely separate procedures with completely independent traits is invalid. Rather, the boundary between them needs to be reflected carefully, as both phases share certain characteristics, being subjected to framing conditions above all (e.g., Stirling 2008). This boundary has been suspected to *"reconstruct the 'deficit model' within deliberative spaces, uphold epistemic asymmetries, reify scientific rationality, or limit engagement to end of science-policy processes to justify pre-formed decisions"* (Chilvers 2008, 178). Therefore, regardless of the respective setting, the concealed reconstruction of knowledge hegemony through boundary work needs to be carefully reflected in order to avoid tendencies of technocracy in participation and societal engagement altogether. As Jason Chilvers puts it:

> *"There is nothing unique about participation that makes it immune from framing effects, the exercise of power, interest-based manipulation, strategic behavior, closing down debate, ignoring uncertainties, and unnecessarily excluding human/nonhuman actors. […] In critically reflecting on the technocracy of participation an important theme that cuts across both analysis and deliberation is the need to ensure diversity, difference, and otherness in participatory appraisal"* (Chilvers 2008, 178, citing Irwin 2001, Pellizzoni 2001, Stirling 2005, Davies 2006a, b).

The constructions of actor roles as well as their boundaries paint a rather varied picture with regard to actors. For my empirical work, this is essential in two ways: first, in that the issues introduced here play an important role in each of my case studies; second, in acknowledging that actor roles and boundaries are *shapeable and changeable*, and bound to specific situations, albeit with overall trends emerging. Thus, in analyzing publics, elites, and imaginaries, a pluralist strategy may bring forth counter-imaginaries of the state, industry, and futures (Hess 2015). Such calls for plurality then eventually imply to break "with traditional dichotomies such as fact/value or knowledge/experience" and create "more long-term spaces of encounters between different knowledge actors […]" (Felt et al. 2013, 28). As actor roles and boundary work fundamentally affect how agency unfolds, overcoming these dichotomies would, by extension, suggest conceiving opening up and closing down in a more dynamic way.

2.3.4. Framing

Framing is the last empirical aspect of participation and societal engagement that I will briefly introduce. Above, this aspect has been lingering in the background as it provides one way of analyzing *power imbalances* in participation and societal engagement and has been well-mobilized in STS literature for that matter. With regard to my thesis, framing provides a sort of metaphorical vehicle to conceptualize opening up and closing down thoroughly. The importance of framing for my analysis lies in the assumption that a *"systematic practical expression of deeply intransigent, tacit structures of power [is] embedded within those cultures of science, technology and their policy circles, including both academic and political habits-of-thought and practice"* (Wynne 2007, 100). Accordingly, Andy Stirling has characterized deliberation as susceptible to issues of power and considered framing even the main mechanism to exert power (Stirling 2008). Thus,

power becomes mirrored in specific structures, either in the way how certain societal cultures manifest, or in narrative structures such as framing.

Framing theory originates from media research and conceptualizes the rhetorical figure of 'frames' or 'framing' in different ways (for a short outline see Bauer and Bogner 2020). Depending on the theoretical approach, framings are either understood as contingencies of how to perceive the world or as actor-specific calls to action (cf. Beland Lindahl et al. 2016, van Mierlo, Beers, and Hoes 2020). As the latter, they serve "social purposes related to the issue at stake, such as putting an issue on the political agenda, mobilising supporters, and presenting specific solutions as self-evident" (van Mierlo, Beers, and Hoes 2020, 365). Framing allows to make sense of ambiguous issues in and through conversations. They make issues salient by *highlighting some aspects* while marginalizing others. To do so, framing not only refers to technical aspects, but to practices and preferences in the respective context (van Mierlo, Beers, and Hoes 2020, 364-365). Thus, framings foreground some features compared to others and provide a background against which individual arguments can then be contrasted. Consequently, framings imply power imbalances between aspects and define which arguments are deemed valid and which are not, which knowledge counts in a debate, and which doesn't (Stirling 2008). By so doing, the framing of an issue affects who will be involved or excluded in the debate (van Mierlo, Beers, and Hoes 2020, 365).

Having a closer look, being able to question established procedures, meanings, and rights of participation lead to discursive openings, i.e., changes in framing. As Elin Ångman put it: *"discursive openings are moments that are 'markedly different' and where participants see an opportunity for a significant change and question knowledge and procedures, or provide alternatives"* (Ångman 2013, 413, cf. Thackaberry 2004). This requires that power relations shift at least temporarily between actors, i.e., to allow for alternatives in framing (Ångman 2013). However, framing may also support discursive closure, when "a particular view of reality [a particular framing, author's note] is maintained at the expense of equally plausible views" (Ångman 2013, 413). In deliberation, this is usually exerted as "quiet, repetitive micropractices, made for innumerable reasons, which function to maintain a normalized, conflict-free experience" (Ångman 2013, 412, cf. Deetz 1992). One example of discursive closure in STI governance is how participants of engagement activities familiarized themselves with new and emerging technologies: they actively used analogies to shape the discussion on unfamiliar subjects (Schwarz-Plaschg 2018), similar to one of my case studies (Chapter 5).

Overall, framing also orients *deliberation exercises* where it entails far-reaching effects on research and assessment approaches, or broader imaginations. For Stirling (2008), framing closely relates to opening up and closing down as the framing of questions, statements, or engagement activities affects the methods and disciplines considered valid. Also, framing shifts with organizational forms: in uninvited engagement, engaged actors possess sovereignty over framing, while in invited engagement, organizers dominate the design of the activity including the overall framing (Braun and Schultz 2010, Bogner 2012b, Bogner and Torgersen 2015). This entails far-reaching consequences for practical requirements but is also affected by them in turn (Bauer and Pregernig 2013, Delgado, Kjølberg, and Wickson 2011, Spangenberg 2008). As a result, framing *predefines* who should have a say: in particular, technical frames have been criticized for inflicting a preselection of actors (Sulmowski 2017). Framing a question in terms of likelihood of

effects invites other experts (i.e., technical experts), as opposed to framing a question in terms of wider understandings of risks and concerns (i.e., a broader variety of experts, stakeholders or the lay public). Consequently, a multitude of framings ensures engaging multiple actors, which, again, corresponds to ideas of epistemic and normative pluralism and recognizes knowledge and values beyond that of experts or scientists.

In contrast, closing down the framing of an engagement exercise entails far-reaching effects. Highlighting the primacy of positivist scientific analyses may emphasize an overall tendency to measurement, quantification, and control, or result in conservative policy scenarios. For example, Blue (2015) assesses the framing of individual deliberation events against the backdrop of the wider sociotechnical context of climate change. As she puts it, these events eventually reinforce *"a dominant policy frame for climate change that is based on an assumption that climate exists 'out there' in the world apart from our interpretations of it, that it is best addressed by positivist scientific analysis, and that it is amenable to measurement, quantification and, ultimately, control"* (Blue 2015, 158). Thus, she concludes that a technocratic approach to policy limits democratic engagement and leads to an unwarranted confidence in the (limited) solutions proposed. Likewise, Rickards et al. (2014) argue that complexity in scenarios reinforces dominant policy approaches which "delay decisions or deny the validity or relevance of unwelcome information or alternatives" (Rickards et al. 2014, 598). Here, dismissing some futures by framing the need in terms of 'policy-relevant' scenarios eventually results in mostly conservative policy scenarios. Accordingly, *shifting framings* in policy is particularly challenging. One example is the understanding of 'innovation' as promoted by R(R)I. Here, 'innovation' is largely defined in techno-economic terms, which results in a marginalization of other forms, like social or attitudinal innovation (von Schomberg and Blok 2019, for the historical development of the innovation concept see Godin 2016, Godin 2008). Hence, framing 'innovation' in this way entails far-reaching consequences, in particular when considering the impact of R(R)I on research through the European Commission's funding activities.

All these examples illustrate the effects of framing, in particular the tendency of activities to continue alongside established policy lines if framings are closed down. This is precisely the challenge that Andy Stirling (2008) seeks to counteract by promoting a meta-level reflection through opening up previously closed down framings. This reflection may play out in different ways: for example, shifting the very framing of analysis, i.e., focusing on vulnerability instead of risk analysis, affects how threats are considered in policy scenarios and allows to move towards more participatory approaches (Rossignol, Delvenne, and Turcanu 2015, 135). Likewise, reflecting on sociotechnical imaginaries (Jasanoff and Kim 2015) in future studies sheds light on the framings that coordinate STI governance, socio-technical systems and actors. In this context, socio-economic imaginaries appear as implicit instruments of governance by using foresight processes "to legitimise certain policy approaches inside some strictly defined thematic areas" (Ahlqvist and Rhisiart 2015, 102). To open up framings, the authors call for strengthening an 'emancipatory paradigm', supposed to amplify "a meta-level systemic perspective behind all ideologies (e.g. ideology of constant growth) that could distort the outcomes of future exercises" (Ahlqvist and Rhisiart 2015, 95). Therefore, opening up framings beyond individual exercises allows to identify and counter long-lasting and fundamental beliefs on which our society is based. In my empirical work, framing provides a starting point for

analyzing how agency is enabled or constrained, i.e., how situations, perspectives or fundamental beliefs are opened up or closed down. Framing is core for investigating opening up and closing down.

3. The question of opening up and closing down

Keeping the challenges outlined in Chapter 2 in mind, inclusion is not a straightforward formula. Andy Stirling (2008) has introduced the twin concepts of 'opening up' and 'closing down' to indicate remaining tensions: for him, adding more actors or perspectives at the expense of the manageability of processes must be balanced against producing outcomes at the expense of forgotten voices.

> *"When a relatively broad-based appraisal process is oriented toward opening up, then challenges will tend to arise in the sheer number and complexity of open-ended elements. When a relatively broad appraisal process is subject to closing down, on the other hand, then tensions may be expected about the specificity and contestability of the particular axis of closure"* (Stirling 2008, 283).

The aim of my thesis is to investigate these very *phenomena of opening up and closing* down in STI governance. To do so, however, I first need to specify what I understand as 'opening up' and 'closing down'. Like me, other authors also described opening up and closing down as spatial metaphors (e.g., Sulmowski 2017). According to the proverb: "when one door closes, another one opens", we open up access to metaphorical space, i.e., to some topics while closing down others, as soon as we start interacting. My thesis explores the conceptual as well as practical implications of these processes of opening up and closing down. This is particularly interesting for research and practice fields that maneuver at the intersection of STI, governance, and policy. TA or the R(R)I community are just two of fields of practice that frequently emphasize the importance of democratizing STI governance in a meaningful way. As Sykes and Macnaghten (2013) put it, there is *"a growing movement of scientists, policy-makers, science communicators, and science funders who are trying to move to a place where 'business-as-usual' is to open up potentially contentious issues to dialogue and debate with members of the public and other stakeholders to explore ways to negotiate more equitable and considered impacts, more attuned to their seen and unforeseen effects"* (Sykes and Macnaghten 2013, 86). But although opening up and closing down are omnipresent in STS, TA, and R(R)I literature, they are by no means self-explanatory, and their practical implications need further elaboration.

In this chapter, I develop a framework to support applying the concepts of opening up and closing down for studying agency in STI governance. For my work, the concept of Stirling (2008) is central. However, other understandings of opening up and closing down in relation to participation and societal engagement have been put forward, too. Therefore, I first discuss Stirling's concept in detail (section 3.1) and contextualize it in literature (section 3.2). I then formulate my research questions and present how I analyze opening up and closing down as enabling or constraining agency (section 3.3.1). Lastly, I provide the background for my analysis, i.e., the theoretical assumptions of my thesis (section 3.3.2).

3.1. Stirling's notion of opening up and closing down

Stirling's concept is for sure one of the most prominent conceptualizations of opening up and closing down in STS and TA literature and constitutes the starting point of my thesis. Stirling is concerned with how to conduct *social appraisal of technologies* in order to provide *policy advice* for STI governance. His approach aims at overcoming two perceived

dichotomies of STI governance: first, the dichotomy between opening up and closing down, which Stirling both considers important, and second, the dichotomy between analytical and participatory knowledge, which he proposes to combine in STI governance. Overall, he aspires to ensure democratic and justifiable policy advice for STI decision-making by consistently involving different approaches, knowledge bases, and values in governance ('opening up').

Stirling steps right into the debate on deliberative participation and upstream engagement typical for the second half of the 2000s (Macq, Tancoigne, and Strasser 2020). He focuses on processes of social appraisal that *inform* the choices in STI governance and which eventually lead to commitment, rather than the commitment to technology options themselves. Hence, Stirling conceptualizes opening up and closing down in relation to deliberation and discursive structures. Instead of focusing on public debates specifically, Stirling proposes to look at social appraisal more broadly. By assigning a legitimate place to both participation and analysis, he aims at resolving the tension between expertise and participation (see section 2.2.2).

Like Irwin and Wynne before him (see also section 3.2.1), Stirling is inclined to questions of power, in his case within the social appraisal of STI. *Power* manifests in questions of how social appraisal should be conducted. Stirling defines power as "the exercise by one group of social actors of influence, control, authority, command, or dominion over others" (Stirling 2008, 274). Yet, in contrast to conventional perspectives on public debates, where increasing participation often constitutes a way of resolving power imbalances in STI, Stirling considers both analytical and participatory forms of social appraisal susceptive to power. By so doing, he smoothens their dichotomy and highlights that social appraisal is always *intentional*, as it follows different rationales, i.e., a normative, instrumental, or substantive rationale (cf. Fiorino 1990). A *normative* rationale focuses on the process where social appraisal appears as "the right thing to do". Here, the norms of analytical or participatory forms of appraisal differ: while analysis is based on "Mertonian or Popperian norms" like 'value free' and 'sound' science, participation mobilizes aspects of Habermas' 'ideal speech' based on legitimacy, public reason, social learning, authenticity, or reflexivity. A *substantial* rationale is outcome-oriented as its "[e]fforts thus concentrate on the interests of specific constituencies, institutions, or technological systems, irrespective of wider normative values" (Stirling 2008, 269). It aims at achieving better ends and therefore concerns outcomes rather than processes. Likewise, the *instrumental* rationale aims at securing specific ends, yet does not aspire to define "explicit, socially deliberated, publicly reasoned evaluative" criteria for the appraisal's outcome. With regard to each rationale, power plays out in different ways:

> *"[n]ormative democratic imperatives aim to ameliorate the effects of wider power inequalities. Instrumental imperatives tend to support ends conditioned by proximate power structures. Substantive imperatives are ostensibly blind to power, focusing instead on apparently transcendent qualities such as precaution or robustness"* (Stirling 2008, 274-75).

To analyze power, Stirling proposes to look at how social appraisals are framed, i.e., how the respective discourse is shaped. *Framing* emphasizes the selectivity of social appraisals: it defines which questions they answer to and which approaches they apply. Accordingly,

the framing of a social appraisal can either allow for opening up or closing down. For Stirling, opening up and closing down are opponent modes. Closing down is supportive of existing power structures as it instrumentally assists "incumbent policy-making actors […] by providing a means to (weak or strong) justification" (Stirling 2008, 278). Here, potential controversies and diversities are obscured to provide clear policy advice in STI governance. Consequently, policy advice is restricted to only a few of all possible courses which are privileged due to specific framing conditions. This has the "instrumental merit of conveying clear, practical justification for decision making" (Stirling 2008, 279). In contrast, opening up reveals "inherent indeterminacies, contingencies, capacities for agency" to wider governance discourses; appraisal results are sensitive to different framing conditions and assumptions (Stirling 2008, 279).

> *"Instead of focusing on unitary prescriptive recommendations, appraisal poses alternative questions, focuses on neglected issues, includes marginalized perspectives, triangulates contending knowledges, tests sensitivities to different methods, considers ignored uncertainties, examines different possibilities, and highlights new options"* (Stirling 2008, 280).

Hence, opening up entails *plural and conditional policy advice*, including alternative courses of action, and relates them to "the real world of divergent contexts, public values, disciplinary perspectives, and stakeholder interests" (Stirling 2008, 280). By so doing, it is supposed to eventually contribute to legitimate, transparent and socially robust decision-making, i.e., closure. Moreover, even when results of the appraisal turn out ambiguous, the remaining selection of options can be considered collectively robust.

Most notably, Stirling's concept of opening up and closing down introduces the issue of *persistence* into the debate: it is not only concerned with the input into debates, but rather with how appraisals and their outputs are presented and carried through, throughout the process. In Stirling's words:

> *"The breadth or narrowness of appraisal concerns the range of inputs that are included (such as issues, possibilities, perspectives, and options). The opening-up or closing-down orientation of appraisal, on the other hand, concerns the range of outputs that are* sustained in parallel and conveyed to wider governance" (Stirling 2008, 282, emphasis by author).

Thus, Stirling distinguishes between broadening out or narrowing down, i.e., getting broader or more limited input in terms of actors or perspectives, and opening up or closing down, i.e., sustaining a broad or narrow range of outputs in parallel. By distinguishing input from output, Stirling highlights the complexity and variability of appraisal practices. Breadth and opening up, or narrowing and closing down do correspond, at least to a certain degree: involving a broader range of actors in appraisal increases the likelihood of more varied output as actors are supposed to represent their own interests and perspectives.

Stirling's concept acknowledges that both opening up and closing down have a role to play in social appraisal processes. After all, opening up ensures that social appraisal remains a pluralist endeavor, while closing down ensures that it eventually results in a subsequent commitment for concrete technology options. To enhance transparency in decision-making, the ideal sequence would first allow for opening up before closing down eventually: *"an opening-up approach may still nonetheless illuminate the potential for*

pursuing a greater diversity of technological pathways […] [and eventually] offer a fruitful basis for further appraisal oriented more explicitly toward closing down" (Stirling 2008, 281). Thus, opening up is supposed to ensure that closure, while inevitable, does not affect appraisal right away.

However, despite acknowledging the importance of both opening up and closing down in appraisal and commitment, Stirling's concept takes a clear *normative position* in favor of strengthening opening up in social appraisals. Moreover, he argues that social appraisal exercises generate a systemic effect and "contribute some diversity and dynamism in technology governance" (Stirling 2008, 284). In practice, STI governance is complex as opening up and closing down may occur at different instants in different places where "[c]ontrasting balances will be judged appropriate in various contexts under different perspectives" (Stirling 2008, 285). Consequently, neither social appraisal nor technology commitment need to be complete. Instead, Stirling emphasizes that innovation may be rendered more robust by pursuing a diversity of technological pathways resulting from manifold processes of opening up or closing down simultaneously (Stirling 2008, 285).

3.1.1. Stirling's reception in literature

To explore Stirling's reception in literature, I conducted a review[8] and found that Stirling's approach has been well-received among scholars in the context of STI governance and sustainability. In particular, the results of the review addressed STI development and assessment, policy advice and policy-making, and related imaginaries, visions and worldviews. Stirling's work is referenced in various research areas, like urban studies, environmental and sustainability studies including studies on energy transition (e.g., Martinez 2020), and even computer sciences (Jirotka et al. 2017), as well as STI policy (Sarkki et al. 2013, Irwin, Jensen, and Jones 2013, Nielsen 2016). In particular, the literature is concerned with specific aspects of participation and societal engagement, like expert knowledge and diversity (Foley et al. 2020), the construction of actor roles (Toogood 2013, Kurian, Munshi, and Bartlett 2014), or the role of public engagement for transforming policy and science institutions (Carvalho, Pinto-Coelho, and Seixas 2019). My review presents a range of methodologies that account for diversity and inclusion, from deliberative focus groups (Macnaghten and Szerszynski 2013), to situational analysis (Glück 2018), Q-method (Brown and Dillard 2015, Kurian, Munshi, and Bartlett 2014), and multi-criteria analysis (Stirling 2010). Stirling's concept has also been deployed in the context of assessment approaches, including risk assessment (Stirling and Scoones 2009), innovation assessment (Hasselbalch 2018), sustainability impact assessment (Martinez and Komendantova 2020), technology assessment (Decker and Fleischer 2012), or vulnerability analysis (Rossignol, Delvenne, and Turcanu 2015). With regard to theory, STS and social sciences have discussed Stirling's concept in relation to actor-network-

[8] This section is based on a systematic literature review (for a description of the method see annex), complemented by individual publications identified via snowball system. The review shows how Stirling's concept has been received in social science literature to anchor my thesis by shedding light on the ways how the concept is mobilized. However, the review cannot claim to be exhaustive. For example, it remains restricted to STS literature on participation; as a result, wider sociopolitical and sociotechnical contexts, e.g., political conditions are underrepresented (with exception of, e.g., Brown 2015, Macq, Tancoigne, and Strasser 2020), as are in-depth theoretical and conceptual debates (with exception of, e.g., Fairhead 2018, Sovacool et al. 2020) or discourses from other academic areas (e.g., economics).

theory (Parker and Street 2015), co-production (Sarkki, Heikkinen, and Karjalainen 2013), sociotechnical pathways (Rosenbloom 2017), and framing theory (Beland Lindahl et al. 2016).

The broad reception of Stirling's concept indicates its *increasing relevance* for different contexts. For my thesis, two aspects that are frequently highlighted in the literature appear particularly important: first, the assumption that complexity requires tentative approaches to decision-making, and second, the need to explicitly negotiate the values on which appraisals are based since they are highly politically entrenched.

Complexity requires tentative approaches to decision-making

The first aspect addresses the challenge of decision-making in a *complex world*. Complexity, uncertainty and ignorance characterize decision-making contexts of technologies, and new and emerging technologies in particular. Stirling's appraisal process allows to gather and weigh different kinds of evidence to inform STI governance. To do this in an inclusive way, decision-making needs to consider input as well as output-related plurality, i.e., broadening out and opening up (Ely, Van Zwanenberg, and Stirling 2014). Their *dynamics* provide insights into how perspectives are aligned or polarized, marginalized or pushed, and how they affect, enhance or limit the inclusiveness of appraisal processes and technology commitments altogether. Accordingly, scholars have called for a systematic opening up of appraisal processes: *"'opening up' to divergent publics, values, priorities, and meanings presents the only way rigorously to validate the range of contrasting framing conditions typically displayed in appraisal under uncertainty, ambiguity, and ignorance"* (Stirling and Scoones 2009, 14). Appraisal may emphasize properties like reversibility, flexibility, and diversity in contending policy instruments (Stirling and Scoones 2009). Therefore, tentative and humble approaches to decision-making in STI governance are important to allow for adjusting technology paths. Consequently, I understand opening up and closing down as dynamic: they are *stabilized temporarily* instead of constituting definite conditions for agency in STI governance.

Appraisals of technology are politically entrenched

The second aspect concerns the insight that social appraisal, including (risk) assessment, are politically entrenched and *performative*. The ways in which appraisals and assessments of technologies vary, provide a valuable starting point for my own analysis. Opening up (or closing down) then addresses approaches and methods used for appraisal, as well as the scope of assessment itself.

As any activity, analyses and assessments are deeply political in the sense that their choices in design are value-based (Hartley and Kokotovich 2018, Stirling, Hayes, and Delborne 2018, Hasselbalch 2018). Accordingly, their epistemic cogency can be changed, as can the legitimacy of applied methods and perspectives. For example, Stirling and Scoones (2009) propose to counter the hegemony of 'science-based' decision-making in the context of disease ecology and management of avian influenza. They link different approaches to inform decision-making, i.e., reductive-aggregative, participatory or precautionary, to different states of not-knowing, like risk, uncertainty, ambiguity, or ignorance. By so doing, they argue that mapping sources of variability in evidence and connecting them to specific framings can make values and interests in the interpretation visible, and eventually leads to an opening up of appraisal (Stirling and Scoones 2009, 8).

In another example, Rossignol, Delvenne, and Turcanu (2015) propose to open up the scope of assessment itself, from risk to vulnerability. This affects how the system under threat is conceptualized: as the (vulnerable) protective good itself rather than hazard (Rossignol, Delvenne, and Turcanu 2015, 130). However, they conclude that such a shift requires embracing complexity and uncertainty. This, again, remains a challenge for political decision-making which appreciates stability and durability of (assessment) systems. Moreover, vulnerability assessment allows for a consideration of values, i.e., by combining quantitative and qualitative assessments including participatory approaches. Yet, current approaches still tend to reproduce a managerial vision of participation. Consequently, vulnerability analysis remains dependent "on classical, science-based, and technical risk-based approaches", where framing conditions remain under-reflected (Rossignol, Delvenne, and Turcanu 2015, 135). Both Stirling and Scoones (2009) and Rossignol, Delvenne, and Turcanu (2015) show how a shift in scope affects how agency is enabled or constrained. In particular, these two examples argue in favor of strengthening the political quality of assessment, i.e., to explicitly negotiate methods and scopes of assessments.

As I understand opening up and closing down as *conditions for enacting agency*, their political quality, i.e., their negotiability, is at the center of my thesis. Roughly speaking, opening up and closing down are processes of inclusion or exclusion on a social, epistemic and normative level, and concern actors, topics and values. Opening up counters tendencies of technocracy, i.e., a dominance of instrumental rationality, while closing down strengthens them. Technocracy is characterized by communicative styles "of most experts and professionals even in . . . innovative [deliberative, insertion original] fora" (Chilvers 2008, 178, referencing Burgess, Harrison, and Filius 1998, 1448). To open up tendencies of technocracy, they need to be carefully reflected on to "ensure diversity, difference and otherness in participatory appraisal [of technology, author's note]" (Chilvers 2008, 178). Against this backdrop of assumed technocratic tendencies, I place emphasis on how opening up and closing down enable or constrain agency in STI governance.

3.2. Questioning opening up and closing down

Stirling's concept is one of the most prominent approaches of opening up and closing down in STS and TA literature, albeit neither the only nor the first one. While it is a useful and lucid starting point, it is helpful to also review earlier notions on which opening up and closing down build, as well as their adaptation in specific contexts like R(R)I. Thus, this section introduces different conceptualizations of opening up and closing down: as selective discourse emphasizing specific framings (section 3.2.1) and as empirical rather than normative phenomena (section 3.2.2).

3.2.1. Conceptualizing opening up and closing down as selective discourse

To conceptualize opening up and closing down, Stirling (2008) draws on earlier work in relation to participation and societal engagement. In particular, he adopts the idea of opening up and closing down as *discursive* phenomena from work of earlier scholars. By using framing to analyze power structures, he once more emphasizes the political element of mechanisms of exclusion through selective discourse.

To summarize this argument, I use Sulmowski (2017)[9], who analyzes opening up and closing down in the context of public debates on genetically modified organisms (GMOs) in Poland. He bases his understanding on the works of Brian Wynne (Wynne 2001, 2003, 2005, 2007) and Alan Irwin (Irwin 2001, 2006). For Sulmowski, opening up and closing down relate to a metaphorical interpretation of space: they imply that something does (not) receive space, and allow for shifting their scope. This means that opening up and closing down entail opportunities for actors to engage in STI processes. Hence, like Stirling, Sulmowski (2017) conceptualizes opening up and closing down in relation to a *virtual discursive space*: this space, again, is constructed through actors, subject positions of participating actors, options for action and meaning. Opening up or closing down constitute more or less of these components: opening up then means a bigger variety of actors, the possibility to change subject positions, to generate as many options for action as possible, and discussing ambivalences or fixed meanings.

Sulmowski (2017) points out that in the context of public debates closing down happens in a non-transparent way, affecting the relation between science and politics. He outlines how the predominant selection of one framing – risks – marginalizes other framings on an epistemic level by considering them 'cultural', 'normative', or 'ethical'. On a social level, this assumes an asymmetry in knowledge and knowledgeability, and, as a result, introduces a distinction between actors, i.e., experts and lay people. On a symbolic level, this distinction addresses the natural and cultural realm more broadly. As politics is located in the cultural realm only, this limits what can be politically negotiated and decided upon, i.e., the very core of politics (Sulmowski 2017, 145). To conceptualize public concerns as 'ethical' or 'cultural' rather than 'epistemic' denies public actors to be knowledgeable about health or ecological risks, and renders their concerns prone to public negotiability. In turn, scientific knowledge does not relate to the ethical realm and, thus, remains non-negotiable:

> *„The ethical dimensions of the scientific knowledge culture itself, including its own self-delusions and lack of reflexivity about the quality of knowledge it provides, and of its own organizational forms of ownership, control and direction, are thus silently deleted from problematization as public issue requiring public deliberation"* (Wynne 2001, 457-58).

Consequently, while public concerns are *marginalized on an epistemic level*, the scientific discourse loses its ethical dimension, which, according to Wynne, could provide normative elements for public negotiation. Thus, to frame issues as risks makes them prone to be addressed by scientific methods and to solidify as "facts". As Wynne put it:

> *„While even the technical, let alone the social, meaning of what we call 'risk' as an object of risk assessment and management is always open to social definition and construction […], this basic epistemic and social contingency is obscured by the dominant scientistic cultural reification of risk as if it were an independently existing object with its own autonomous meaning, to be revealed, analysed and controlled as such by scientific discipline"* (Wynne 2005, 70).

[9] Unfortunately, this book is only available in German. The title translates to: *Controversial practices in a public controversy. Closures of negotiation spaces in the agro-genetic engineering debate in Poland*.

In line with Wynne, Sulmowski (2017) calls for rendering visible the normativity of sciences instead of understanding science as "culture of no culture", which denies the negotiability of scientific facts: "[a]gainst this background, a non-recognition of normativity of entities can be understood as a de-thematization of negotiability"[10] (Sulmowski 2017, 152, translated by author). Drawing on Latour (2008), Sulmowski (2017) argues that the distinction between facts and values, while constitutive for modern societies, has a closing down function. By being considered a part of the natural realm and, thus, to be able to "let facts talk", science appears apolitical. As a result, science is allowed to decide over political matters outside of publicly legitimized decision-making. Risk assessments is one such example. Here, experts usually hold power in framing and conducting and attempts to open up practices are only slowly being established (Hartley and Kokotovich 2018, Klinke and Renn 2021).

In short, science serves as a starting point for public deliberation without being subjected to public deliberation itself. One strategy to counter this tendency is to address the boundary between facts and values to expand the scope of politics again. This can even be considered a political act itself: "The problematization of de-thematizing the negotiability, as well as the other forms of closing down, are therefore always linked to a specific understanding of politics and democracy"[11] (Sulmowski 2017, 156, translated by author).

This argument outlines the political elements of selective discourse and how they entail mechanisms of exclusion in public debates and STI governance. It constitutes the backdrop of Stirling's concept and provides the starting point for my thesis to look at how agency is enabled or constrained. However, as I am interested in the very mechanism of opening up and closing down, my thesis does not only address public discourse, but looks at STI governance more broadly, including contexts of R(R)I.

3.2.2. Conceptualizing opening up and closing down as empirical conditions

In STI governance, Stirling aims at a balanced approach between opening up and closing down in the social appraisal of technologies, which eventually cumulates in technology commitments. He proposes to include participatory approaches consistently, countering mechanisms of exclusion in STI governance and conceptualizing opening up and closing down in a normative way. However, existing work has brought some challenges and interpretations to the framework of opening up and closing down: first, in terms of conceptualizing opening up and closing down empirically, and second, as dynamically intertwined phenomena.

Regarding the first, scholars have recently pointed out that appraisal conditions in the private sector fundamentally differ from those in STI governance, and with them the relation between opening up and closing down. In particular, the *role of closing down shifts*: Tempels and van den Belt (2016) pointed out that closing down is essential for business practices. In that light, they criticized social sciences in that *"[c]ritical social scientists have perfected the art of questioning framing assumptions, but have largely ignored the difficult task of bringing a public debate to a timely conclusion"* (Tempels and

[10] Original: „Eine Nicht-Anerkennung von Normativität von Entitäten kann vor diesem Hintergrund als eine De-Thematisierung der Verhandelbarkeit verstanden werden."
[11] Original: „Die Problematisierung von De-Thematisierung der Verhandelbarkeit wie auch der übrigen Formen der Schließung ist somit stets an ein bestimmtes Verständnis von Politik und Demokratie gekoppelt."

van den Belt 2016, 138). Van Mierlo, Beers, and Hoes (2020) revisit Stirling's concept in the context of responsible innovation. Here, inclusion is central: deliberation relates to motivations for and goals of technology development (van Mierlo, Beers, and Hoes 2020, referencing Stirling 2008, Stilgoe, Owen, and Macnaghten 2013). Yet, the private sector is subject to specific conditions that limit the suitability of deliberation (also see Scholten and Blok 2015, Brand and Blok 2019). Consequently, the authors question assumptions that appear less ambiguous in STI governance contexts: the assumed positive relation between a wide inclusion of actors and opening up (van Mierlo, Beers, and Hoes 2020, mobilizing Jamison and Wynne 1998, Wynne 2007); and the comprehensive normative calls for opening up (Stirling 2008, Ely, Van Zwanenberg, and Stirling 2014). Instead, they favor more modest approaches to opening up (e.g., Stilgoe, Owen, and Macnaghten 2013, Irwin, Jensen, and Jones 2013). Rather than considering opening up as desirable *per se*, they highlight the importance of closing down to reduce complexity and ambivalence, and to steer innovation. Thus, van Mierlo, Beers, and Hoes (2020, 362) balance opening up against closing down, referring to the efficacy paradox of complexity[12] (Voß, Bauknecht, and Kemp 2006). Besides, they argue that opening up and closing down can occur simultaneously, highlighting their *dynamic relationship*. Referencing Walker and Shove (2007), they emphasize that *"forms of opening up also represent moments of closure (and vice versa). In addition, it supposes that debates, problems and questions can be 'opened' and closed at will"* (Walker and Shove 2007, 222-223, van Mierlo, Beers, and Hoes 2020, 364). In short, the depiction of opening up and closing down in the context of responsible innovation differs radically from Stirling's account. In particular, van Mierlo, Beers, and Hoes (2020) criticize his normative stance and suggest treating opening up and closing down as *empirical conditions* with complex relations. They are then temporary, rather than durable, occur simultaneously, and are often mutually constitutive. All these characteristics require to study their dynamics in-depths.

For my thesis, I draw from a combination of both understandings, Stirling's normative commitment and van Mierlo et al.'s conception of opening up and closing down as mutually constituted. I do so by shifting the focus of analysis from overall and normative procedures to the micro-dynamics of opening up and closing down. R(R)I is characterized by an undirected normative call for openness (of science and research) in the light of maintaining an innovation paradigm (Nerlich, Raman, et al. 2018). R(R)I activities assume a linear innovation model, starting with open upstream engagement before any decisions are taken. At the same time, micro-dynamics like the framing of a debate or rhetoric outlines of future developments come into play. Thus, I look at opening up and closing down as consecutive sequences of technology appraisal. At the same time, I understand them as phenomena that simultaneously shape agency within individual settings along the innovation stream, adding to the empirical perspective sketched out above.

Regarding the second, the emphasis on the *empirical quality* of opening up and closing down strengthens this focus on their dynamics. One example in the context of anticipatory practices, i.e., future studies, is the study of Urueña, Rodríguez, and Ibarra

[12] Van Mierlo, Beers, and Hoes (2020) explain the efficacy paradox as follows: "The requirement to simultaneously maintain openness and close down to retain the ability to act. Opening up risks losing an action perspective, while the risk of closing down is to be blind towards relevant considerations, ambiguity and controversies" (van Mierlo, Beers, and Hoes 2020, 367).

(2021). Like Sulmowski (2017), they used the metaphor of space, but exceed the scope of public concerns by encompassing the whole range of potential futures: thus, opening up and closing down refer to the "amplitude of space for alternative 'plausible' and/or 'desirable' futures" (Urueña, Rodríguez, and Ibarra 2021, 11). The authors conceptualize opening up and closing down as empirical phenomena: instead of absolute conditions, they constitute extreme positions of a gradient. Here, individual situations can be indicated, which designate "[t]he degree of 'openness/closure' of anticipatory practices" (Urueña, Rodríguez, and Ibarra 2021, 11). Moreover, opening up and closing down appear rather variable, regarding the subjects of investigation as well as their manifestation: *"[t]his 'opening-up' occurs in multiple domains (outcomes, processes, purposes and/or expectations/ visions/ imaginaries), and according to different radicalisation gradients"* (Urueña, Rodríguez, and Ibarra 2021, 9).

Thus, the concept of opening up and closing down becomes more variable and dynamic in what it entails. While Sulmowski's and Stirling's conceptualizations remain restricted to the virtual discursive space, Urueña, Rodríguez, and Ibarra (2021) identify multiple levels where opening up, i.e., the co-negotiation of established constraints is potentially located, and reiterate the importance of consistently opening up:

> *"This amplitude [of space for alternative futures, author's note] is enabled during the (de)construction of futures in light of the heterogeneous technical, methodological, axiological, volitional, socio-material, epistemic and/or affective constraints explicitly or implicitly established and/or co-negotiated* during the whole process*"* (Urueña, Rodríguez, and Ibarra 2021, 11, emphasis by author, also see Urueña 2019).

Thus, Urueña, Rodríguez, and Ibarra (2021) remarkably extend the scope of opening up and closing down by taking into account the heterogeneous constraints that affect and constitute these phenomena. With regard to my own work, considering opening up and closing down as *dynamic and multi-leveled* highlights once more the importance to study them as empirically entwined.

Overall, the literature that I have reviewed here has conceptualized opening up and closing down with regard to different realms (i.e., as virtual discursive space) and aspirations (i.e., as normative or empirical phenomena), scopes of time (in terms of the extent of future-orientation, as well as whether they occur subsequently or simultaneously), and stabilization (i.e., temporary or definite stabilizations). My own conceptualization of opening up and closing down as *enabling or constraining agency* mobilizes these prior concepts in a specific way. I consider opening up and closing down as *empirical phenomena* that not only moderate virtual discursive spaces but *a broader range of manifestations* of discourse alike (for theoretical assumptions of my thesis see Section 3.3.2). Here, opening up describes a consistent endeavor to widen the scope. I also understand opening up and closing down as relative, rather than absolute, and temporary, rather than definite, stabilizations of conditions for agency in STI governance. Moreover, while opening up and closing down can well be conceptualized as subsequent steps of a linear process, zooming in on each of them will allow to paint a more dynamic picture where opening up and closing down relate to each other in different ways. In this thesis I will tease out these dynamics with regard to enabling and constraining agency in STI governance.

3.3. Research question and approach

My thesis follows the literature in tracking opening up and closing down in different contexts to investigate their dynamics. Much of the research outlined in the previous sections follows Stirling's normative account and looks at how opening up can be achieved. In contrast, I explore how opening up and closing down are constituted in different settings of STI governance of emerging technologies. In addition to understanding them as subsequent steps of an appraisal process as suggested by Stirling (2008), I take their simultaneity into account, and look at how they relate to each other, their dynamics and mutual dependencies between them, and how they manifest in STI.

3.3.1. Research question and dimensions of analysis

Based on the assumptions outlined above (section 3.1 and 3.2), I am interested in how the phenomena of opening up and closing down shape STI and STI governance. To do so, my overall research question is:

- How are opening up and closing down constituted in different settings of STI governance of emerging technologies?

To answer this question, I address the following sub-questions:

- What does it mean to open up or close down?
- How do opening up and closing down manifest in different instances of STI?
- How do opening up and closing down relate to each other?
- What are implications of the dynamics of opening up and closing down for participation and societal engagement, and STI governance more broadly?

Essentially, my thesis sets out to advance the outlined literature in three regards: first, to combine analysis of deliberation with other mechanisms that are relevant to STI governance processes; second, to exemplify the role of technology assessment (TA) in relation to opening up and closing down; and third, to distinguish between different dimensions that are mobilized in the context of opening up and closing down in order to explore the dynamics more clearly.

First, as outlined above, Stirling's concept of opening up and closing down focuses on social appraisal of technologies. It emphasizes deliberation about the technology at stake to support decision-making rather than technology formation.

As indicated above, my thesis does not share this sole emphasis on deliberation. Rather, I am also interested in other *instances alongside the innovation stream* where opening up and closing down play a role. Consequently, I do not only consider conventional efforts at organizing deliberation, but put additional emphasis on (a) the analysis of narratives (i.e., myths) as one vehicle to move deliberation upstream, and (b) the analysis of technology (i.e., computational models) itself, as well as the negotiations it builds upon. To do so, I select a case-study-based approach to compare the phenomena of opening up and closing down along the innovation stream at different instances of STI (for a discussion of the stream metaphor see section 2.3.2). By so doing, I am particularly interested in whether and how the dynamics between them change. However, these additional emphases require *adapting analytical concepts* to capture their peculiarities. To look at the phenomena of opening up and closing down further upstream, I use the concept of myth formation as public heuristic and introduce the concept of affordances for analyzing technology development (for details see Chapter 4). By so doing, I aim to develop

a comprehensive view on mechanisms of opening up and closing down alongside instances of STI governance.

Second, *governance instruments* have their own merit in strengthening or weakening tendencies of opening up and closing down in STI governance. TA in particular could ensure plurality, transparency, and legitimacy of processes since its methods allow for combining technical analysis with participation (Ely, Van Zwanenberg, and Stirling 2014). This, however, depends on the form of TA at hand, i.e., parliamentary or participatory, and *"there is scope for questioning whether current high profile, newly institutionalising forms of European TA necessarily always display all the claimed properties around broadening out and opening up"* (Ely, Van Zwanenberg, and Stirling 2014, 507). Hence, calls for a systemic view to differentiate STI governance instruments consider TA as but one approach of social appraisal of technology.

For my thesis, the particular focus on TA is relevant as all projects that I selected for analysis understood themselves as dedicated TA projects (see section 4.2). Opening up and closing down is a prime opportunity to contribute to questions of TA at the intersection between conceptual advancement and practical implications. TA's dualist interest has been addressed in the contrasting of Stirling (2008) and van Mierlo, Beers, and Hoes (2020), which highlighted the shifting relation between opening up and closing down in different STI contexts. Most TA projects, including the ones that my thesis is based upon, set out to contribute to democratizing STI governance. Yet they hardly aim at democratizing governance systematically and are often bound to a practice-oriented agenda. Thus, while opening up and closing down have immediate and important practical implications for TA, I am convinced that insights can be deepened by looking at the phenomena of opening up and closing down in a conceptual way as well.

Third, I will take a closer look at how aspects of opening up and closing down *interrelate*. By so doing, I treat opening up and closing down as empirical phenomena rather than a normative approach. Stirling (2008) argues that framings manifest power aspects in social appraisal by explicitly highlighting specific aspects while marginalizing others. This back- and foregrounding activity shapes which arguments and methods are considered appropriate for the task at hand and defines how agency is enabled and constrained in the respective situation. Accordingly, Stirling and Scoones (2009) have argued that "the systematic 'opening up' to *divergent publics, values, priorities, and meanings* presents the only way rigorously to validate the range of contrasting framing conditions typically displayed in appraisal under uncertainty, ambiguity, and ignorance" (Stirling and Scoones 2009, 14, emphasis by author). Thus, the aspiration to open up implies considering multiple aspects to ensure a valid argument in favor of plurality. Therefore, appraisals should be subjected to systematic opening up to investigate how issues at stake are framed (Stirling and Scoones 2009). In my thesis, I contribute to such a systematic investigation by disentangling a range of dimensions in which processes of opening up and closing down can be manifested.

To take an even closer look at the dynamics of opening up and closing down, I systematically address the individual dimensions that framing relates to. These dimensions allow me to analyze who introduces a particular framing, as well as the arguments and perspectives on which each framing is built. These dimensions are easily deducible from the aspects outlined above: 'divergent publics' indicate social aspects, while 'values, priorities and meanings' relate to normative aspects; whereby 'meaning' implies

epistemic aspects as well. Therefore, I will explore aspects of the social, epistemic and normative dimensions in my case studies to gain insights into the dynamics between opening up and closing down.

- *Social dimension – "Actors and roles":* First, I investigate the actors who are considered relevant in negotiations and developments in STI governance. Including a broad variety of actors in participation and societal engagement has served as approximation to inclusive and socially robust decision-making (see e.g. Owen et al. 2013, von Schomberg 2013). Particularly when issues are potentially conflicted, the question of who is invited or whose standpoints are considered, is crucial. Thus, the literature on invited engagement emphasizes the importance of considering different actor groups, and their knowledge bases and perspectives respectively, for STI governance. Stirling (2008) is mobilized in relation to individual engagement activities. Among other aspects, in this context the literature addresses the construction of actor roles and the importance of diversity in engagement activities to enrich expert-based rationales (Foley et al. 2020, Toogood 2013, Kurian, Munshi, and Bartlett 2014). Moreover, in most assessment approaches, including a variety of actors serves as a starting point for bringing in a variety of epistemic and normative aspects. However, some authors challenge the correlation between increased number of actors and variety of perspectives and aspects (e.g., van Mierlo, Beers, and Hoes 2020).

  Therefore, I investigate aspects of the social dimension by focusing on the actors involved: Who is participating in the respective setting, or is considered respectively? In what contexts and forms is public or stakeholder engagement being practiced and their perspectives considered?

- *Content-related and epistemic dimension – "issues and forms of knowledge":* Second, I will look at issues and forms of knowledge that are considered relevant in the case studies of my thesis. The aspect of *issues* defines the problem at stake by designating what is being negotiated or needs to be left unsaid as soon as actors have commonly identified and accepted fundamental problems, notions and concepts. *Forms of knowledge* define which kind of expertise and which knowledge claims are accepted in deliberation, and hence, are being operationalized. In the literature, both aspects are considered closely intertwined and are primarily addressed in relation to methods, i.e., as pleas to better integrate different forms of knowledge or assessment approaches (Stirling and Scoones 2009, Stirling 2010, Decker and Fleischer 2012, Ely, Van Zwanenberg, and Stirling 2014, Rossignol, Delvenne, and Turcanu 2015, Hasselbalch 2018, Martinez and Komendantova 2020).

  In my thesis, I am interested in which contributions are considered valuable, reliable, or debatable, and which arguments count as arguments in the respective situations. I ask which knowledge is taken for granted and which knowledge claims must be justified, which knowledge is considered enriching, and which is considered negligible. Thus, I will focus on questions like: which issues are brought to the fore? What are the concepts that understandings are based on and what kinds of knowledge are considered?

- *Normative dimension – "Orientations and values":* Third, normative aspects have increasingly gained attention among scholars and practitioners, particularly in the context of STI governance and R(R)I (Owen et al. 2013, von Schomberg 2013). Therefore, I will look at the values and norms that orient the arguments in emerging technology debates. While overarching normative orientations like sustainability, safety, or inclusive technology appraisal are easily agreed upon, negotiating trade-offs between individual options remains challenging. Literature on participation and societal engagement, including Stirling (2008), has extensively argued that analytic and participatory approaches are equally value-based. Moreover, with regard to democratic legitimacy of decision-making, literature has discussed the value-base of perspectives, interests, agendas, or framing.

  Therefore, my thesis investigates values and orientations that actors consider in their arguments and how they relate to opening up or closing down. I will do so by addressing questions like: which values and normative ideas orient public/stakeholder engagement, implicitly or explicitly? How are they expressed and formulated?

Disentangling these three dimensions analytically promises to lead to new insights into the dynamics between opening up and closing down. They allow to analyze opening up and closing down in STI and STI governance, in particular with regard to participation and societal engagement. For example, I will demonstrate that instead of being equally important the three dimensions affect opening up and closing down in different ways.

At the same time, opening up and closing down broaden the focus on participation and societal engagement by drawing attention to how they manifest. Here, the concept of agency comes in: in my understanding, the question of how agency is enabled or constrained does not only relate to plain deliberation or dialogue with stakeholders or the public. Rather, with regard to STI, it also addresses subtler mechanisms embedded in narratives or sociomaterial configurations. Accordingly, I broaden the scope of my thesis to include public sense-making as well as sociomaterial configurations in my considerations of agency.

Hence, investigating a range of settings instead of focusing on one in particular promises interesting insights on how openness and closure are applied. Accordingly, for my thesis, I chose a case-study approach (see Chapter 4) to highlight the distinctive aspects of STI governance and to mirror the multitude of situations where opening up and closing down occur. How do inclusive settings and epistemic and normative aspects relate? How is the framing of the respective issue affected if settings become more (or less) inclusive? By addressing these questions, my work sheds light on how dimensions of opening up and closing down relate. However, before I outline my research design and the empirical details of my case studies, I will discuss the theoretical backdrop on which my empirical work is based.

3.3.2. Theoretical assumptions of my thesis

In this section, I present the basic theoretical assumptions of my thesis. I first discuss how I conceptualize technology's entanglement with the social sphere. I then explicate my approach to agency, and the ideas of discourse and dialogue on which participation and

societal engagement are based. All these assumptions are important in relation to my empirical work, yet in different ways: conceptualizations of 'technology' remain lurking in the background and vary considerably, while the concepts of 'agency', 'discourse' and 'dialogue' are mobilized more directly in relation to my case studies.

Technology as sociomaterial and sociotechnical phenomenon

The first conceptual question to address is how technology is defined in my thesis. What is technology and how does it come about? How does it affect its context? Is it due to the shape or form of the respective object? Due to evoking its imagined properties? Or simply due to the intention of how to use it? And what about non-physical entities, like computational programmes? Where does 'technology' begin and where does it end?

These and many more questions emphasize the importance to look at what is meant by 'technology' and how it relates to sociality. A basic insight of STS is that technology does not develop independently from society. Rather, it is contingent on social and cultural configurations, and affects them in turn (cf. Pinch and Bijker 1984, Latour 1990, Law 1992, Hughes 1987, 1994, despite fundamental differences in how they conceptualize these relations). Moreover, how technologies are perceived shapes *how agency unfolds*: when perceived as malleable, technology allows actors to steer its development and articulate different demands – provided one follows a human-centered perspective (see below). Such demands range from orienting technology towards desirable outcomes, to stimulating processes of learning, coercion and negotiation, or changing processes involved in technology development (Rip and Kemp 1998, 390-391). Assuming malleability, science and technology are neither *"external determinants of social order [...] [nor can] social structures [...] explain scientific and technological developments without further ado"*; rather, they are *"mutually constituted in one and the same historical process"* (Habers 2005, 13).

To structure the long-standing debate of how to conceptualize technology for my thesis, I draw on Leonardi (2012), who discusses materiality, sociomateriality and socio-technical systems by reviewing conceptions of technology, emphasizing its persisting and malleable features, as well as their causes and effects as described in STS literature. He argues that social sciences use notions of '*materiality'* to contrast social constructivist perspectives when they turned out problematic from a practical point of view (Leonardi 2012, 27). In this light, materiality reminds us that *"some aspect of the technology [...] was intrinsic to the technology, not part of the social context in which the technology was used"* (Leonardi 2012, 28). Therefore, materiality combines matter and form, but does not describe materials only (Leonardi 2012, 28). Besides these enduring elements, materiality is also situation-specific as technologies never fully stabilize but evolve over time (see also Orlikowski 2000). Accordingly, *"certain aspects of technological artifacts are materialized when they have consequence in a particular setting"* (Leonardi 2012, 30). Consequently, Leonardi (2012) defines materiality as "[t]he arrangement of an artifact's physical and/or digital materials into particular forms that endure across differences in place and time and are important to users" (Leonardi 2012, 31). Therefore, he emphasizes the materiality of technology as something that "makes certain actions possible and others impossible, or at least more difficult to achieve" with direct consequences on social organizing (Leonardi 2012, 31).

In contrast, '*sociomateriality'* shifts the unit of analysis considerably, "*from materials and forms to the* development or use *of materials and forms. […] Thus, whereas materiality might be a property of a technology, sociomateriality represents that* enactment of a particular set of activities *that meld materiality with institutions, norms, discourses, and all other phenomena we typically define as 'social'*" (Leonardi 2012, 34, emphasis by author). Leonardi structures the debate on "sociomateriality" in STS literature according to two overall objectives: *"(a) that all materiality […] is social in that is was created through social processes and it is interpreted and used in social contexts and (b) that all social action is possible because of some materiality"* (Leonardi 2012, 32). For my discussion, the second point is negligible as it is mainly agenda-setting for organization studies, which have largely marginalized technologies by merely focusing on their 'implementation' (Leonardi 2012, 34).

The first point, however, is important. In this regard, the sociology of technology and some representatives of organization studies have offered suggestions: here, Leonardi (2012, 32) lists basic STS theories like social construction of technology (Pinch and Bijker 1984), actor-network theory (Latour 1990, Law 1992), and large technical systems (Hughes 1987, 1994). Organization theorists focused on the merging of artifacts with organizations' social system when they are adopted and used. Here, structurational approaches (Orlikowski 2000, 1992, Poole and DeSanctis 1992, Poole and DeSanctis 2004) met perspectives that emphasized the shaping of the social environment of a technology over time through changes in socially negotiated use patterns (Leonardi 2012, 32-33, referencing Barley 1990, Edmondson, Bohmer, and Pisano 2001, Boudreau and Robey 2005). Eventually, *practices* gained attention as the "sociomaterial is not the technology, but the 'practice' in which the technology is embedded" (Leonardi 2012, 35, see also Orlikowski 2007).

Thus, sociomateriality is closely intertwined with practices which constitute *"the space in which social and material agencies are imbricated with each other and, through their distinct forms of imbrication, produce those empirically observable entities which we call 'technologies' and 'organizations'"* (Leonardi 2012, 38). Thus, by acknowledging that "materiality takes on meaning and has effects as it becomes enmeshed in a variety [of social, author's note] phenomena […]" (Leonardi 2012, 38), the question of (socio-)materiality is linked back to the question of agency (see below).

'*Socio-technical systems'* again emphasize the social context of use which defines to some extent whether and how technology is adopted (Leonardi 2012, 38, see also Bostrom and Heinen 1977, Benders et al. 2006). For example, Rip and Kemp (1998) have argued that conceptualizing technology implies that its immutability is *"the outcome of material and sociocultural configuring, not a property of the artifact as such"* (Rip and Kemp 1998, 329). Accordingly, individual application contexts bring forth different qualities by exceeding the structuring and fixed qualities of technology. As a result, technology can be conceptualized in different ways, as "tangible things and skills", "production technology", "sociocultural/sociotechnical landscape", "a symbol and ideology" (Rip and Kemp 1998), or as artefacts, systems and organizations, reservoirs of knowledge, or symbols (van Lente 2017). Ultimately, to use Leonardi's words, socio-technical systems closely relate to "sociomaterial practice", where *"the abstract properties of a social subsystem could be strengthened or disturbed based on the particular ways in which social and material agencies were imbricated in the technical subsystem"* (Leonardi 2012, 41).

To sum up, Leonardi (2012) distinguishes materiality, sociomaterial practices and sociotechnical systems in that materiality "simply refers to the properties of a technology that are used in various ways to support various tasks in the technical subsystem" (Leonardi 2012, 41). Yet, a socio-technical system refers to "abstract institutional constructs and patterns of sociomaterial imbrication", while sociomaterial practice describes a group's localized experiences around a particular or various technologies (Leonardi 2012, 41).

My thesis will analyze a range of emerging technologies that have 'materialized' to different extents. To simplify the reading experience, I will use the general term 'technology' when referring to the respective combination of technical and social interrelations in each case study. This is necessary since the respective social qualities and the perspective on how to address the respective technology shift between cases. I will mobilize conceptions of technology in two ways: first, from an STI governance perspective and second, looking at the sociomateriality of the technology.

The first conception emphasizes the *political* context of my thesis where its specificities depend on the respective case study. Stirling (2008) links opening up and closing down to policy advice, i.e., to weighing and negotiating evidence. In this case, technology is merely conceptualized as a *symbol,* i.e., as a sociotechnical system that highlights specific application contexts. Technology then constitutes a *discursive* product and provides an entry point for 'important issues' into public policy debates, which imply contestations and deliberation of actors. Hence, it is charged with metaphysical properties and links *"the question of orienting and steering sociotechnical change […] with culturally defined possibilities, and [the question, author's note] which division of labor, cultural codes, and storylines, have become embedded"* (Rip and Kemp 1998, 337). Accordingly, the technology at stake is hardly described in detail, except where properties are used by actors in different ways, symbolizing different pathways for policy or technology (see also Leonardi 2012). Moreover, steering sociotechnical change steers a division of labor between technical development and the rest of society. Technology then becomes accompanied with voices safeguarding its development, based on a societal distribution between praising and blaming sociotechnical change (Rip and Kemp 1998).

The second conception allows to zoom in on the *sociomateriality* of the technology at stake where appropriate, i.e., on how the discourse on a specific issue eventually becomes materialized. I will analyze imaginations of sociomaterial practices and technical properties to explore how the materiality of technology unfolds. This shifts the perspective from STI governance to concrete technologies with Leonardi's definition of materiality covering both the physical and the virtual world (Leonardi 2012). Here, the question of material agency becomes crucial, which depends on the respective function, i.e., the context of the technology. As Leonardi puts it:

> *"What the technology* is *does not change across space and time, but what it* does *can and often changes. Function – or material agency – is a construction that depends, in part, on materiality but also depends on one's perceptions of whether materiality affords her the ability to achieve her goals or places a constraint upon her. Materiality exists independent of people, but affordances and constraints do not"* (Leonardi 2012, 37, emphases original).

Thus, people perceive technology in the light of distinct possibilities (or constraints) for action as "affordances and constraints are constructed in the space between social and material agencies" (Leonardi 2012, 38). How social and material agencies are intertwined then depends on people's choices. Moreover, how closely the technical and the social interrelate in each case fundamentally defines how agency of humans or non-humans is enacted.

Agency

The second assumption of my thesis addresses the concept of agency. Agency is a central concept in social sciences, from economic to political studies, and as such is highly debated. For a general introduction, I turn to Emirbayer and Mische (1998) since they conceptualize agency as *emerging, relational, and structurally enabled*, characteristics that are particularly helpful when looking at sociotechnical phenomena. However, for individual case studies, I use additional concepts inspired by more specific accounts of agency (i.e., actor-network-theory) to highlight the interrelation of different actors.

In line with the broader debate on agency, Emirbayer and Mische (1998) define agency as a capacity that exceeds individual actors' activities: it encompasses the conditions or the potential to act and goes beyond concrete action (Emirbayer and Mische 1998, 1004). They look at how actors change "their degrees of flexible, inventive, and critical response toward structuring contexts" to indicate their capacities "to mediate the structuring contexts within which action unfolds" (Emirbayer and Mische 1998, 1012). To do so, they explore the iterative, projective and practical-evaluative element of agency to make visible agency's dynamic relation to structure (Emirbayer and Mische 1998, 963). To do so, Emirbayer and Mische (1998) consider agency as relational: it is a consequence of relations between actors, rather than an intrinsic property of an entity. Moreover, agency is temporal, as it is embedded in social engagement were the present contextualizes both "past habits and future projects within the contingencies of the moment" (Emirbayer and Mische 1998, 963).

Most notably, *agency and structure* are related and affect one another as actors are able to move between contexts and temporal orientations and thus (willingly) change their relation to structure (Emirbayer and Mische 1998, 964). Hence, agency and structure are neither in opposition nor "'mutually constitutive' in a direct and stable way" (Emirbayer and Mische 1998, 1002). Rather, they dynamically relate to each other as conditions structure orientations of actors. As Emirbayer and Mische (1998) summarize it:

> *"[T]he double constitution of agency and structure"* consists of *"temporal-relational contexts support[ing] particular agentic orientations, which in turn constitute different structuring relationships of actors toward their environments. It is the constitution of such orientations within particular structural contexts that gives form to effort and allows actors to assume greater or lesser degrees of transformative leverage in relation to the structuring contexts of action"* (Emirbayer and Mische 1998, 1004, emphasis original).

Emirbayer and Mische (1998) place emphasis on the dynamics between actor and structure, and conceptualize agency as human agency of individual or organizational actors. Accordingly, technology depends on (inter)human goals, intentions, interests, or power relations (Habers 2005, 17). However, looking at sociotechnical development, the

assignment of agency changes. In particular, actor-network-theory (ANT) has re-conceptualized society as a heterogeneous network of actors (Latour 1990). It "focusses on the hybridity of socio-technical collectives, on the heterogeneous networks, the imbroglios of human and nonhuman 'actants'" (Habers 2005, 15). However, like with Emirbayer and Mische (1998), agency still remains a relational quality distributed among (human and/or non-human) entities instead of being assigned an a priori property (Habers 2005, 18).

In my thesis, agency foregrounds the *activity potential* in negotiating and developing emerging technologies that depend on respective historical, political, cultural, or technical constraints (Fairhead 2018, Stirling 2008). Rather than the individual activity of actors, I look at the mechanisms that enable or constrain their agency. Thus, the perspective of opening up and closing down supports focusing on the conditioning elements that allow for specific patterns of agency.

Accordingly, opening up and closing down serve as approximations to enable or constrain agency. Here, agency constitutes an aggregate of different mechanisms that imply a certain 'power to act'. Conceptualizing agency as such an aggregate entails that opening up or closing down do not necessarily always affect agency in an immediate manner, but shape the conditions of its formation. Thus, agency exceeds understandings of power to *act* and also refers to subtler mechanisms like framing, the use of language, and individual speech acts. Upfront, the understanding of agency in my thesis is human-centered: if technologies are perceived as malleable, this suggests human hegemony over technology rather than the emergence of agency out of heterogeneous networks. However, this perspective changes between the case studies of my thesis to a certain extent and highlights the specific (policy or technology) contexts they are located in. In particular, the concept of affordances promotes a less human-centered perspective on agency.

Most notably, how agency is enabled and constrained is affected by the degree to which the discourse has been stabilized at the moment of investigation. These constraints vary qualitatively and quantitatively: qualitatively regarding the kind of ties between the respective discourse and STI, quantitatively in terms of the flexibility of conditions for STI. Accordingly, openness and closure differ in relation to the form and extent to which the discourse is stabilized and manifested in STI at the moment of investigation. This, in turn, defines the boundaries in which opening up and closing down occur.

Discourse and dialogue

The third conceptual question of my thesis relates to assumptions about discourse and dialogue. Investigating phenomena of opening up and closing down essentially boils down to the general question of how to organize public space. More specifically in the light of inclusion, the question remains how to best conceptualize emerging technologies and how they are negotiated. Stirling (2008) locates the phenomena of opening up and closing down in the *discursive* realm and uses framing to analyze power constellations in negotiations of perspectives. As outlined above, my thesis expands beyond this focus on discursive space only. In addition, I neither aim to contribute to the theoretical discussion on discourse or dialogue, nor provide a comprehensive discourse analysis. However, societal engagement, in particular with regard to R(R)I, cannot be discussed without references to more basic theories on discourse and dialogue. Yet, how these terms are understood, varies considerably between different conceptualizations.

The central figure for theorizing discourse is Michel Foucault. He is particularly interested in the role of scientific discourse, i.e., discourse on truth, but eventually relativizes its specific status compared to others. In *The Order of Discourse* (Foucault 1970/1981), he argues that *any* social discourse is controlled, i.e., that its access is restricted. Discourse is neither open nor inclusive, but exclusive. Thus, discourse evokes issues of *political and societal legitimacy* and legitimization: which perspectives are legitimate to be raised, which are not? What is left unsaid or undesignated altogether? How do positions become accepted by others? What are requirements to conduct discourse? In his theory Michel Foucault emphasizes the social embeddedness of discourse. Discourses are instruments of producing individual and collective subjectivities. They are more than individual speech acts; they are the expression of one's embeddedness in the world. Discourse provides lines of argumentation that actors draw upon to build their arguments. And actors do not select anchor points of their perspectives randomly: whether consciously or not, they always relate to specific social discourse. Therefore, discourse is enacted through participants, and, as a result, cannot be thought distinct from their social or political positions.

Discourse means a '*totality of statements'* with universal characteristics and functions, based on the idea that knowledge about the world is always mediated in a discursive way. The notion of 'discourse' can refer to such a totality on various levels: first, it can refer to the overall totality of statements; second, to individual groups of statements, where each subject constitutes of a variety of discursive subjects, e.g., regulatory and scientific discourse; or third, to a regulated practice that brings about a specific field of statements defined by conditions for a specific practice (Parr 2020). While all three understandings designate far-reaching discursive practice, the latter two emphasize its linguistic side, as they relate to specifics part of knowledge (Parr 2020, 274).

Internal dynamics of discourse consist of the specific rules that the practice of thinking, writing, speaking, and acting follow which systematically produces the subjects that discourse is about. Moreover, discourses are formed by external mechanisms, like strategies of exclusion through upholding distinctions (e.g., 'normal' and 'not normal'), forms of regulation that describe procedures to reduce discourse (e.g., by specific knowledge production at institutions like university), and access to discourses (e.g., through formal qualification). These external mechanisms link the theory of discourse to the theory of power by relating to other discourses and elements of social practices. Foucault introduces the concept of the 'dispositive' to describe the strategic unification of knowledge formation, institutions, and technology (Parr 2020, 275). As Parr emphasizes:

> *"Discourses are* materially *traceable forms of social speech that are specialized and institutionalized according to practice fields, which implies that discourses always show distinct rules of formation and exclusion and with individual operativity. This implies a relation between aspects of speech and action which brings forth the question about the relation between discourse and power"*[13] (Parr 2020, 275-276, translation and empahsis by author).

[13] Original: *„Diskurse sind materiell nachweisbare Formen gesellschaftlicher Rede, die stets nach Praxisbereichen spezialisiert und institutionalisiert sind, so dass es Diskurse mit distinkten Formations- und Ausschließungsregeln und jeweils eigener Operativität gibt. Dabei besteht zwischen dem Rede- und dem Handlungsaspekt von Diskursen ein Zusammenhang, womit sich unmittelbar die Frage nach der Relationierung von Diskurs und Macht stellt "*(Parr 2020, 275-276).

By asking about effects of power, discourse analysis allows for *intervening* in discourse, e.g., through undermining existing or promoting alternative discourse (Parr 2020, 276).

A totally different understanding of discourse (from the German *Diskurs*) is the concept of Jürgen Habermas. Habermas' philosophy of *'rational communication'* in the political realm is summarized in his 'models of democracy' (Habermas 1992). Yet, his ideas of political legitimacy have been discussed early on. They are based on the assumption that legitimate *norms can be justified* argumentatively in an unforced way (Fach 1974, 221) while marginalizing empirical conditions of the very act. Habermas defines a specific procedure, dialogue[14], which requires specific situations and certain dispositions of participants to eliminate conflict. Dialogue is supposed to ensure that norms assert dominance solely based on the force of 'the better argument', eventually resulting in a 'truthful' consensus (Fach 1974, 222). Such an *'ideal situation of speech'* is free of any kind of external or internal force and only follows the better argument without any deception. Accordingly, dialogue characterizes a situation of speech rather than inherent characteristics of participants. To arrive at this 'unforced force of the better argument', dialogue requires specific conditions, including no time pressure, being relieved of a force to action, relativizing perspectives, and symmetric opportunities to participate. Dialogue is thought to complement established institutions and structures as it is able to universalize interests agreed upon. Since it potentially confirms existing norms and values, it can prove their legitimacy (Fach 1974, 223-224).

Recent ideas on how dialogue should be conducted to constructively contribute to STI governance largely rely upon Habermas' idea of 'rational communication'. It underpins ideas of participation and societal engagement, in particular in the form of invited engagement that is core to R(R)I (Lozano and Monsonís-Payá 2020). Accordingly, Stirling's perspective relies on Habermas' 'ideal speech', in particular when participation adheres to the normative rationale and is supposed to allow for legitimacy, public reason, social learning, authenticity, or reflexivity.

Stirling locates the phenomena of opening up and closing down in the *discursive* realm, where he sets out to analyze power through framing. Thus, his understanding of discursive relates straight forward to a negotiation of perspectives and puts actors' agency at the center of his approach. Accordingly, his concept of power is actor-based as well: for him, it is "the exercise by one group of social actors of influence, control, authority, command, or dominion over others" (Stirling 2008, 274). Power is concrete and depends on the relation between different actors or actor groups.

As Stirling is at the center of my conceptual approach, my thesis builds on this notion but aims at *enriching the reflection* on opening up and closing down with the help of Foucault and Habermas. However, I do not claim to pay dues to the complexity of discourse theory nor the theory of rational communication. This would exceed the scope of this thesis by far. Also, by putting technologies at the center of my thesis instead of focusing on negotiations only, concepts of dialogue and power in relation to opening up and closing down need to be adjusted. Foremost, my thesis relates to concepts of discourse in relation to *dialogue as imagined by R(R)I*. Here, it pays attention to how actors speak about a specific issue (expert/public discourse about technology X) or how a specific technology is addressed more generally (technology discourse). However, in some case

[14] As the German 'Diskurs' is often translated with 'dialogue' rather than 'discourse', I will use this term from now on.

studies, I consider the material level as well since it is being shaped by accumulations of discursive acts. Therefore, my thesis exceeds the spoken realm and also addresses technologies as manifestations of discourse and discursive practices.

Accordingly, the concept of power in my thesis needs to be adjusted. Overall, power is crucial for defining which issues can be problematized and how, and how the social conditions for developing or speaking about a technology are formed. These conditions limit what one can say or do (or not), and thus, are a prerequisite to foreground aspects of framing. In contrast to Stirling, Habermas and Foucault both conceptualize power as going beyond personal interaction, although their concepts of power differ fundamentally: power is not (only) exercised in concrete, interactive settings, but constituted through the respective social context. Roughly speaking, for Foucault, power is executed through concepts and notions provided by discourse; for Habermas, through adhering to the logics of the specific societal subsystem under investigation (state/capitalist economy). However, both emphasize that power manifests in *structures as well as interaction*, albeit to different degrees. This perspective allows analyzing power not only in direct interaction (like Stirling) but also in relation to organizations, discourses, and not least, sociotechnical phenomena.

Expanding Stirling's focus on "justificatory narratives" (Gerritsen, Savini, and Revilla 2020, 36) allows studying opening up and closing down in relation to sociotechnical phenomena, i.e., different manifestations of technology discourses. To do so, my thesis is (roughly) inspired by notions of both Habermas and Foucault. From Habermas' concept of dialogue, it takes how certain engagement activities should be organized, as mirrored in ideals of invited engagement activities under R(R)I. From Foucault, it takes the conceptualization of discourse as the totality of all that is being said and done, including sociotechnical developments and STI governance, and the emphasis on the social embeddedness of discourse. And both inspire to look at how structural power pervades sociotechnical contexts.

4. Research design and method

So far, I have given an introduction to participation and societal engagement in STI governance (Chapter 2), and presented the conceptual framework of my thesis including research questions, dimensions of analysis, and theoretical assumptions (Chapter 3). Therefore, I will now introduce the research design and method for my empirical work (Chapters 5-7).

4.1. Research design of the thesis

Opening up and closing down are well received in literature and my review (see Chapter 3) has shown the diversity of research areas that operationalize them. This diversity testifies to the importance of opening up and closing down and it resonates in my research question, too: *How are opening up and closing down constituted in different settings of STI governance of emerging technologies?*

In literature on participation and societal engagement, opening up and closing down are frequently applied to individual exercises, sometimes contrasted against a wider political background (for example see Blue 2015). While such individual studies provide valuable insights, much may be gained through a more comparative and comprehensive approach to opening up and closing down. My thesis focuses on revealing structural characteristics such as power and/or knowledge constellations in negotiation and technology development. To do so, I reconstruct how these characteristics manifest, allow for alternative framings of a technology at stake, or raise (implicit) expectations of specific stakeholders. Therefore, this thesis may reveal established common practices and blind spots in STI governance. To be able to follow individual and collective interpretations, and to ensure the allocation of meaning by individuals or groups, I selected a qualitative research approach based on case studies.

I chose a *case study approach* to investigate how opening up and closing down manifest in different 'moments' of STI development. Case studies have been described to "emphasize the rich, real-world context in which the phenomena occur" (Eisenhardt and Graebner 2007, 25, cf. Bos 2016). Moreover, case study research is suitable for investigating contemporary phenomena which occur outside the control of the researcher, or doing exploratory research that addresses questions of 'how' and 'why'" (Shakir 2002, 191). As my empirical work meets these characteristics, case studies allow for an in-depths investigation of opening up and closing down.

Case study research builds on a *sound selection of cases* based on 'purposeful sampling', which identifies information-rich cases to use limited resources effectively (Patton 2002). As Palinkas et al. (2015) state, individuals and groups of individuals for case study research need to be identified and selected. These individuals need to be "especially knowledgeable about or experienced with a phenomenon of interest"; in addition, they need to be available, willing to participate, and able to "communicate experiences and opinions in an articulate, expressive, and reflective manner" (Palinkas et al. 2015, 534). Palinkas lists different purposeful sampling designs, including *"the selection of extreme or deviant (outlier) cases for the purpose of learning from an unusual manifestations of phenomena of interest; the selection of cases with maximum variation for the purpose of documenting unique or diverse variations that have emerged in adapting to different conditions, and to identify important common patterns that cut*

across variations; and the selection of homogeneous cases for the purpose of reducing variation, simplifying analysis, and facilitating group interviewing" (Palinkas et al. 2015, 535). To ensure that my case studies comprehensively cover the subject of my research, I aimed for *'maximum variation'* to first, mirror the broad range of opening up and closing down as indicated by the literature review (Chapter 3), and second, to ensure a comprehensive and thorough investigation of these phenomena through cross-case analysis.

Across all cases, the *analyzed data* varied (for more details please see the respective case studies and the section on the research process below), from interviews to observations and notes gathered in focus groups, to a variety of public dissemination material (e.g., deliverables from EU projects, scientific literature, online media articles, communication documents such as policy briefs etc.). At the core of the empirical work of my thesis are the interviews and focus groups that I conducted in each case. They allow for insights in reasoning and complement written and published communication in particular regarding procedural aspects.

One challenge of interventionist research, however, is to confront interview partners and focus groups with unfamiliar situations, provoking artificiality in responses and behavior. Since all interview partners operated in spaces prone to public justification (e.g., applied research, civil society organizations, etc.), this can be considered less of a factor since they were used to relate their work to aspects of public relevance (in the widest sense; see also conditions for purposeful sampling above). In the case of the focus group setting, i.e., when working with students and teachers, this was more relevant. To minimize negative effects on the setting, a few measures were taken (see below).

4.2. Case study selection

My thesis investigates different aspects and conceptualizations of emerging technologies. I consciously selected the case studies related to different technologies (neuroenhancement, synthetic biology, nanotechnology) to account for the breadth and variability of emerging technologies. Moreover, this illustrates the temporality of STI and allows to investigate patterns of opening up and closing down across the case studies.

I am well aware that conceptualizing STI processes in a *linear manner* has been harshly criticized for good reason (see e.g., Rip and Kemp 1998, Stirling 2008, von Schomberg 2013, von Schomberg and Blok 2019). Yet, it allows to emphasize the aspect of time dynamics in my thesis (see also section 2.3.2). The interventions on which my case studies are based were selected to illustrate different moments of impetus and institutionalization of the respective technology discourse. These interventions range from early upstream deliberation about abstract technology concepts (neuroenhancement) to downstream negotiations on concrete issues in multi-stakeholder dialogue (synthetic biology), or to the mediation of issues of public concern (computational modelling for risk governance of nanotechnologies). Each of these interventions relates to a different stage of technology development and discourse. As a result, they each allow for reconstructing opening up and closing down in relation to specific objects of analysis, namely: narratives, stakeholder dialogue, and a virtual artefact. By so doing, my thesis provides insights on similarities and differences on how opening up and closing down occur in individual cases as well as in comparison. This allows for a deeper look into these phenomena, accounting for the variability of discourses in STI governance.

To set the scene, I will shortly *sketch out the technology discourses* at the time the respective case studies were conducted before discussing the set-up of each intervention in more detail. Aspects of opening up and closing down play out differently in each, due to the variety in technologies under discussion and the perspectives based on the interventions of each case. The debate on neuroenhancement serves as an example of early-upstream engagement and respective governance; the contestation around synthetic biology illustrates how arising technological approaches and products on the verge of marketization become subject to public negotiation; and the debate about nanotechnology concerns a technology which has been monitored since day one and has affected STI governance in general.

Regarding neuroenhancement, public discourse in Europe was almost non-existent at the time of investigation (2013-2016). This makes it a textbook example of early upstream public engagement: characterized by high uncertainty and ignorance, hardly available sound knowledge on approaches or their consequences and effects, potentially high ethical ambiguity, as well as unclear public stakes as the technology shows only little relation to questions of everyday life. Nonetheless, governance institutions (among them the European Commission) showed increasing interest in the human brain (e.g., the FET flagship project 'the Human Brain Project' of the EC[15]), which drove the issue of neuroenhancement to unlock the brain's remaining capacities.

Synthetic biology, in contrast, has already been on the agenda of governance institutions since the early 2010s, with the UK at the forefront establishing public discourse and governance[16]. While applications were developed in public and private research, the issue of synthetic biology remained publicly contested as questions of environmental and human safety, social impacts and long-term effects had not been settled yet. In addition, synthetic biology was (and still is) embedded in a variety of wider contexts (e.g., biodiversity). This debate provides insights about a technology on the verge of being consistently governed: while uncertainty in knowledge decreases, ethical ambiguity remains and a variety of governance institutions and approaches have been developed to address these issues. The case study on synthetic biology captures a moment in discourse where a rather abstract umbrella term becomes more tangible through applications developed in public and private research, and therefore, easier to grasp for public scrutiny.

Nanotechnology, as a third example of a technology discourse, has evoked interest of social sciences, political sciences, and regulation since the late 1990s (at least). Nanotechnology fundamentally challenged concepts of how to govern emerging technologies, risks, and uncertainties and well-established practices of policy-making and policy advice based on (sound) science. The discourse on nanotechnology (or, later on, nanoparticles and nanomaterials) has coined ideas of anticipatory governance (Guston 2014), strengthened pre-emptive modes of governance and policy-making (Åm 2015), and laid the foundations for a broader reflection on how STI could be conducted responsibly (Owen et al. 2013, von Schomberg 2013). Consequently, the discourse on nanotechnology,

[15] https://www.humanbrainproject.eu/en/about/overview/ (accessed 06 September 2021).

[16] As illustrated by initiatives like the Synthetic Biology Leadership Council (https://www.gov.uk/government/groups/synthetic-biology-leadership-council [accessed 06 September 2021]) or the Synthetic Biology Public Dialogue (https://bbsrc.ukri.org/documents/1006-synthetic-biology-dialogue-pdf/ [accessed 06 September 2021]).

specifically the discourse on risk governance of nanomaterials and nanoparticles, provides an example where a technology discourse is at the verge of being settled and translated into regulatory activities. Yet, individual aspects (e.g., how to conduct efficient risk assessment and management) still remain unresolved and offer opportunities for new technical approaches like computational modelling.

4.3. Data gathering based on interventions: research projects

The data on which my case studies are based stems from different research projects I was involved in during the last couple of years (2015 – 2020). I will shortly provide an overview in this section.

4.3.1. Case study 1: Myths on neuroenhancement as public sense-making based on the NERRI project

The NERRI project (03/2013 - 05/2016) aimed at fostering the deliberation on neuroenhancement between societal actors. As part of the Mobilization and Mutual Learning Action Plan, the project consortium (18 partners in 11 countries) organized over 60 events throughout Europe, ranging from panel discussions to debates with Parliamentarians to public events using card games to facilitate the deliberation process. The team of ITA-ÖAW (including the author of this thesis) was responsible for the synthesis of a 'White Paper on the Responsible Research and Innovation in Neuroenhancement' addressed at the European Commission among other things. However, the main task of the ITA-ÖAW team was to set up public deliberation events in Austria, addressing different actor groups. At that time (2015-2016), the prevalence of established practices of neuroenhancement in Austria (and Europe for that matter) was rather low and remained unclear due to potential off-label use of medical substances (e.g., methylphenidate).

As research on neuroenhancement practices (referring to substances as well as devices) most likely implied a trade-off between a desired increase of specific brain function (e.g., concentration) and the decrease of others (e.g., social behavior), the ITA-ÖAW team chose a deliberation setting that would most likely be affected by such trade-offs. To do so, we selected an educational context for the intervention on which we built our subsequent analysis (Chapter 5). We did so for two reasons: first, we considered the educational context to be demanding in content and socially; second, we assumed that it was future-oriented, at least to some extent (the students were about 16 years old). To account for different educational environments, we based our analysis on focus groups with teachers and students in two types of schools, where we expected differences in evaluating (school) performance: the first school was a business school, the second one explicitly focused on integrating students with special needs. The selection of the field and the respective participants were based on the hypotheses that (a) teachers may be prone to use neuroenhancement in their daily lives, torn between intellectually and socially challenging work (considering the suspected trade-off between enhancing one capability of the brain and lowering others); (b) teachers' observations of teens' habits may provide interesting insights; and (c) due to their youth students may be open to experimenting with substances or devices (for studying, or for leisure activities, such as gaming).

The deliberation exercise aimed at identifying pressing issues about neuroenhancement, including the necessity and potential strategies of governance. By working with groups in a familiar social environment (e.g., students as a class or teachers

among colleagues), we hoped for rather 'authentic' deliberation as neuroenhancement turned out to be rather difficult to grasp for participants. Yet, their general unfamiliarity with the topic, as well as the set-up of the deliberation (including the fact that my colleagues and I were introduced as 'scientists') may have affected how the discussion evolved.

As shortly addressed above, the team of ITA-ÖAW conducted a range of further activities, such as expert interviews to inform the deliberation events and two expert workshops (both not at the core of my thesis). In the second workshop (held in July 2015 in Vienna), experts from neurology, cognitive psychology, pharmacology, ethics, social sciences, philosophy, and the educational context discussed the results of the focus groups and provided context regarding the technical state-of-the art, prevalence, daily practices of neuroenhancement and deriving implications for regulation.

Table 1: Summary of the NERRI project

The NERRI Project	
Project	Neuroenhancement and RRI
Acronym	NERRI
Duration	2013-2016
Funding	EU – FP 7 (Grant agreement no 321464)
Partners	Ciência Viva (project coordinator), London School of Economics, Radboud University Nijmegen, King's College London, European Brain Council AISBL, Scuola Internazionale Superiore di Studi Avanzati, Instituto de Biologia Molecular Celular, Genetic Alliance UK, Experimentarium, Haskoli Islands, Stichting Katholieke Universiteit Brabant Universiteit van Tilburg, Fondazione Toscana Life Sciences, Közép-európai Egyetem, Universität Stuttgart, Universitat Pompeu Fabra, Johannes Gutenberg Universität Mainz, Universität Linz.
ITA-ÖAW Team	Helge Torgersen (project lead at ITA-ÖAW) Daniela Fuchs Anja Bauer
Website	http://www.nerri.eu/ (outdated), for more information see[17]

As my colleagues and I were involved in setting up and conducting the very intervention that the neuroenhancement case study is based on, we refrained from taking the intervention *per se* as object of analysis (as I did in the other two case studies of this thesis). Rather, we took a meta-approach and focused on the interpretative mechanisms and sense-making that became visible in the deliberation workshops, which we interpreted as myths-making.

The case study on technology myths emphasizes on the performative power and effect of narrative structures, with its social level (actors and roles) predefined through the overall focus on public sense-making. Early upstream engagement is characterized through high (scientific) uncertainty and its interpretational freedom depends on the

[17] https://cordis.europa.eu/project/id/321464/reporting/de (accessed 26 July 2021).

societal context of the respective technology. Therefore, I am particularly interested in the transfer of meaning and embedded values through technology myths.

4.3.2. Case study 2: Engagement of civil society organizations in synthetic biology based on the PROSO project

The PROSO project was concerned with potential changes in societal engagement under the RRI framework regarding specific actor groups, namely third sector actors (civil society organizations - CSOs, and the general public). PROSO aimed at fostering the early engagement of CSOs and citizens in research and innovation systems in Europe under the terms of RRI. The case study of this thesis is based on the work I conducted on CSO engagement in the debate on synthetic biology during the PROSO project.

The discourse on synthetic biology at that time, as indicated above, had already been established (depending, of course, on the respective national context). For example, the UK had spent considerable amounts on initiating public dialogue[18] (Bhattachary, Calitz, and Hunter 2010), establishing policy guidance on the issue (e.g., through publishing the UK Synthetic Biology Roadmap and establishing the Synthetic Biology Leadership Council[19]), institutionalizing research on synthetic biology as well as accompanying research to enhance reflexivity[20], while other European countries were more reluctant to fund the 'label' of synthetic biology. Within the PROSO project, my colleagues and I selected three cases in the field of synthetic biology to study the engagement of CSOs.

Besides conducting the PROSO case studies, the ITA-ÖAW team was responsible for a variety of different tasks, foremost for a literature review on societal engagement under RRI (Bauer, Bogner, and Fuchs 2021) and conducting engagement with lay people on different technologies in Austria.

Table 2: Summary of the PROSO project

The PROSO Project	
Project	Promoting Societal Engagement under the terms of RRI
Acronym	PROSO
Duration	2016-2018
Funding	EU – H2020 (Grant Agreement no 665947)
Partners	Dialogik Stuttgart (project coordinator), Applied Research and Communications Fund, University of Surrey, Sociedade Portuguesa de Inovação, FoodDrinkEurope, Universität Stuttgart, Optimat Limited.
ITA-ÖAW Team	Alexander Bogner (project lead at ITA-ÖAW) Daniela Fuchs Anja Bauer
Website	http://www.proso-project.eu/ (accessed 21 July 2023)

[18] https://bbsrc.ukri.org/documents/1006-synthetic-biology-dialogue-pdf/ (accessed 06 September 2021).

[19] for more information see: https://www.gov.uk/government/groups/synthetic-biology-leadership-council (accessed 06 September 2021).

[20] see the UKRI (BBSRC and EPSRC) synthetic biology research centers established in 2014: SBRC-Nottingham, SynthSys (Edinburgh University), OpenPlant (John Innes Centre and Cambridge University), WISB (University of Warwick), SynBioChem (University of Manchester), BrisSynBio (University of Bristol). https://www.sbrc-nottingham.ac.uk/about/about.aspx (accessed 08 September 2021).

This case study investigates invited and uninvited engagement formats with CSOs taking on different roles in each setting. The settings I selected for my thesis differ slightly from the ones carried out in the project to emphasize the issue of opening up and closing down more consistently: one setting focuses on a public protest against household products (potentially) containing synthetic biology components; another one, triggered by this conflict, features a top-down multi-stakeholder dialogue, and a third one is organized as upstream deliberation under RRI. This case study sketches how CSOs engage in debates on emerging technologies (like synthetic biology) in different settings. It investigates how different forms of engagement contribute to opening up or closing down. To do so, it focuses on the interrelations between the actors involved, formats and framing of the respective deliberation settings.

4.3.3. Case study 3: Investigating affordances in modelling for nanotechnology risk governance based on the CoMoPA project

The CoMoPA project was concerned with the role of computational modelling for policy advice and investigated computer modelling and simulation as instruments and practices of epistemic, social, and political ordering. The project addressed questions of the epistemic, social, and political meaning along two interrelated themes, namely the science(s) of modelling and the power of modelling. The present case study of this thesis (nanotechnology risk governance) is one out of three (the other ones being concerned with energy transition and transnational trade policy).

Besides the stakeholder interviews that this cases study is based on, the CoMoPA project conducted social network analyses to sketch out the wider scientific discourse of the respective case and explored novel approaches for text analysis (topic modelling). The findings of these analyses were validated through expert interviews and a qualitative text analysis of scientific publications to embed the findings in the wider field.

Table 3: Summary of the CoMoPA project

The CoMoPA Project	
Project	Computational Modelling for Policy Advice
Acronym	CoMoPA
Duration	2018-2020
Funding	ÖAW Innovation fund
Partners	None
ITA-ÖAW Team	Anja Bauer (project lead at ITA-ÖAW) Daniela Fuchs Leo Capari Titus Udrea
Website	https://www.oeaw.ac.at/en/ita/projects/computational-modelling-for-policy-advice (accessed 21 July 2023)

Thus, the third case study of this thesis investigates how a specific modelling tool affords shifting ideas of assessing risks, governing emerging technologies, and designing the relations between science and policy-making. In short, it investigates the performativity of computational models and their development process. To do so, it looks at stakeholder engagement and expertise (i.e., the social dimension), as well as concepts (i.e., the

epistemic dimension) at the core of the tool and concludes the deriving normative assumptions the tool is built upon.

4.3.4. Summary of the three case studies

In each of these projects, my colleagues and I carried out interventions, either through setting up deliberation formats or through conducting interviews. Yet, the levels of analysis each relate differently to these interventions. To provide an overview over all three case studies, Table 4 below summarizes the three case studies of my thesis regarding their discourse characteristics, the origin of data, and the level of analysis applied.

Table 4: Summary of the case studies of the thesis

Scope of Case Study	Myths in the making	Multi-actor deliberation	Development of modelling tool
Technology under investigation	Neuroenhancement	Synthetic Biology	Computational Modelling for Nanotechnology Risk Governance
Discourse characteristics	Very early upstream dialogue	Dialogue comprising upstream and downstream elements	Discourse mediated through affordances
Data origination	Observation/ facilitation/ analysis of focus group deliberation	Expert and stakeholder interviews & document analysis	Expert and stakeholder interviews & document analysis
Level of analysis	Public sense-making (involved in case)	Multi-actor deliberation (not involved in case)	Affordances of a modelling tool (not involved in case)

Looking at Table 4, the variety of discourse characteristics in my thesis becomes immediately visible. As specified above, this is due to the different stages of the respective technology discourses. While following the phenomena of opening up and closing down is appropriate in any of them, they entail some necessary conceptual adaptations.

Stirling (2008) discusses opening up and closing down in relation to the social appraisal of technology including participatory methods, which may be best mirrored in my case study about deliberation of synthetic biology: the focus on actor roles, engagement formats and framing appears rather straightforward in this regard. Yet, my case studies of early-upstream engagement and computational modelling address other levels of discourse. They emphasize narrative structures and socio-material manifestations in addition to deliberation. Accordingly, I explore additional concepts to analyze agency adequately, namely 'myth formation' in early-upstream engagement and 'affordances' in computational modelling. Each concept allows to foreground different aspects with regard to the respective stage of technology development: 'myth formation' emphasizes the importance of narrative structures to familiarize oneself with emerging phenomena; 'affordances' allow to explore socio-material manifestations of discourse.

4.4. Details of the research process

In this section I introduce the individual steps of how I conducted my research, from data gathering to analysis.

4.4.1. Data collection

I collected my data in the run of three research projects (two EU projects, one national project) where I was responsible for a dedicated part of each project (e.g., organizing focus groups or conducting interviews on my own). Before I go into the details of my case studies, I would like to draw attention again to my own role, which shifted considerably between projects (also see above). In case study 1, I took on an interventionist role in conducting the engagement exercises together with my colleague. We were in charge of inviting participants as well as of framing the discussion altogether (e.g., by defining neuroenhancement). In contrast, in case study 2 and 3, I foremost analyzed engagement and research activities of others. To balance between case studies, my colleague and I refrained from analyzing our own intervention in case study 1 and instead focused on mechanisms of public sense-making. In case study 2 and 3, my colleagues and I address the mechanisms of engagement *per se*.

Case study 1 is based on *group deliberation* conducted during the NERRI project where I had the opportunity to organize focus groups. In general, focus groups are suitable to gain insights in subjective structures of meaning against their social context. Due to their internal dynamics, focus groups provide a chance to use group interaction as research data, explicitly providing the researcher with a more specific argumentation. Thus, the neuroenhancement case study is based on focus groups as they are likely to reveal collective attitudes and opinions. Dissent occurring in group discussions may lead to a more explicit argumentation, as the individual needs to justify his or her perspective clearly. However, I am aware that group dynamics may also have adverse effects for data gathering (e.g., by automatically censoring individual perspectives, cf. Kitzinger 1994).

For case studies 2 and 3, my colleagues and I considered *stakeholder interviews and document analysis* the most adequate choice for data gathering. To gain in-depth insights about the cases and to access the meaning-making of the involved actors, we conducted qualitative semi- structured expert interviews (Bogner, Littig, and Menz 2009). They predominantly focused on 'theory generation' (Meuser and Nagel 2009): while exploratory and systematizing expert interviews aim at gathering facts and data, theory-generating expert interviews focus on reconstructing latent meaning, subjective action orientations, and implicit decision-making maxims of actors in specific functional and institutional contexts (Bogner, Littig, and Menz 2009). In my thesis I understand 'expert' in a broader sense, rather than capturing only scientific, technical, or academic experts: 'expert' denotes anyone with a specific knowledge about the issue at stake in a specific situation of circumstance. To identify interview partners, I used a 'snowball' method: several interview partners were identified via desktop research, and the number expanded based on recommendations and further considerations that emerged during the respective case study. In both case studies, a generic interview guide was developed based on the analytical questions and dimensions. Yet, the interview guides remained flexible and were regularly adapted to the individual case and interviewee. During the interviews, I followed the guides loosely depending on the interviewee's willingness to tell on his or her own story

since it is *"the relevance structure of the interviewees, which shall be elicited, not those of the interviewer"* (Meuser and Nagel 2009, 33).

For case study 2, I gathered empirical material through a qualitative content analysis of publicly available documents (such as deliverables, peer-reviewed papers, reports, fact sheets, etc.) and ten semi-structured interviews with the most important actor groups affected by the respective engagement practice (e.g., NGOs, academia in different roles, industry, etc.). I conducted these interviews between November 2016 and February 2017 as part of the project PROSO, mostly via phone/Skype (one was done by a colleague face-to-face); they lasted between 45 minutes and 1,5 hours.

I collected the empirical material for case study 3 through a qualitative content analysis of policy, science and public documents (such as deliverables, peer-reviewed papers, fact sheets, conference proceedings, workshop protocols, etc.) and 16 interviews with experts and stakeholders, i.e., modellers, scientists or political and societal decision-makers. They were either involved as addressees/users/customers, commissioners, input/source or involved in processes informing the modelling, e.g., stakeholder workshops. I conducted the interviews in 2019 as part of the project CoMoPA, via Skype; they lasted between 45 minutes and 2 hours.

4.4.2. Data management and research ethics

Concerning data management, all participants and interviewees were comprehensively informed (in person and in writing) about the nature and extent of the interview and were asked for their written consent prior to the respective activity (focus group or interview). The interviews were anonymized unless consent was given to quote interviewees verbatim.

4.4.3. Analysis of data

The case studies followed a qualitative paradigm as outlined by Bogner, Littig, and Menz (2009). The interviews and focus groups were tape- recorded, transcribed, and interpreted by means of qualitative, hermeneutic methods of content analysis (Mayring 2000).

I analysed the empirical material by qualitative content analysis (which is suitable for all selected data) either using MAXQDA® or conducting the analysis manually (in the case of focus groups; cf. Kuckartz 2016). In general, qualitative content analysis of speech highlights the importance of the content; however, it is also possible to deduct the semantic content and subjective meaning.

In case of the focus groups, I used an *iterative approach* between inductive and deductive analysis. My colleagues and I based the facilitation of the workshop on a (flexible) guideline for deliberation, capturing a few related aspects to trigger discussion (e.g., about potential experiences with neuroenhancement, what problems participants saw arising if neuroenhancement was freely available, whether they had any idea of how to handle neuroenhancement from a regulatory point of view, etc.). This provided anchor points for discussion which allowed us to cluster statements accordingly. The clustering also allowed an inductive approach, to flexibly include new topics in the run of manual clustering to see what aspects would emerge out of the material. In this way we identified and analyzed the most prevalent topics in relation to governance of neuroenhancement in the material. As the analysis focuses on mechanisms of myth-making rather than individual interventions, we did not consider the use of MaxQDA® necessary for coding.

In case of the interviews, I conducted a *qualitative content analysis* by categorizing/coding the empirical material. In a first step, I conducted a qualitative-interpretative analysis and, in a second step, explored whether the coding was applicable to more than one paragraph (see Kuckartz 2016). I then coded interview transcripts according to topics by using the software MaxQDA®: coding was carried out deductively and inductively to allow for both analytical rigour and flexibility to account for unforeseen aspects. While I deducted part of the respective categories from semi-structured interview guidelines, qualitative research approaches remain flexible enough to adapt and complement categories during the working process. Codes both accounted for descriptive categories (e.g., actors involved) and analytical aspects (e.g., boundary management), and specificities of the interviews were noted during the coding process.

In a next step I interpreted the resulting thematic units against the conceptual backdrop of the respective case study. To identify and code the social, epistemic, and normative dimensions, I looked for respective indications. Regarding the social dimension, this mostly addressed the question of who participated in a specific process and the roles they adopted. I examined this question through direct statements (either direct quotes from interviews or indications in documents, i.e., signatures of letters, project descriptions, etc.) or indirect indications drawn from the set-up of the respective engagement setting (in particular case study 1). To follow the question of roles of engagement in practice, re-reading interviews in a comparative manner (within each case study) helped to draw conclusions on the tasks and collaborations between different actors or actor groups and to identify contexts and forms of engagement practices (in particular case study 2 and 3).

Regarding the epistemic dimension, I was interested in the question of which arguments count as arguments, which knowledge was taken for granted, and which knowledge claims needed to be justified. I identified and clustered the arguments, issues, and knowledge bases mentioned in direct statements (i.e., interview statements, reports, etc.) and gained additional information in an indirect way (i.e., analyzing the set-up of the respective engagement setting, or contrasting my findings to academic literature to identify missing issues). To identify and contextualize the concepts to which these aspects relate, I relied on academic literature for the respective cases (i.e., established strands of literature on myth formation and its roles, on CSO engagement, or risk governance and STS critique thereof).

Concerning the normative dimension, I identified values and orientations considered by actors in their arguments more indirectly using questions like: which values and normative ideas orient public/stakeholder engagement? How are they expressed and formulated? In general, focus group participants and interview partners only talked about explicit norms, values, and orientations to a limited extent during their interviews: when talking about considerations on social or ethical impact assessments, public perception of risks, etc., when disclosing expectations of their clientele (i.e., ideas of sustainability as promoted by certain CSOs) or when making references to other comparable practices (i.e., drug abuse, drinking coffee etc.). Therefore, in addition and inspired by the literature, I deduced norms and values from the outlined perspectives and issues. For example, STS literature criticizes a (general) emphasis on 'science-based decision-making' and 'risks' while promoting aspects of 'fairness' or 'democratization'. Thus, I identified respective statements and perspectives and looked for related aspects (i.e., a quanitification of risks, transparent communication, etc.) or contrary features (i.e., alternative perspectives

highlighting aspects of social fairness like livelihoods of farmers, aspects of non-expert participation, etc.). By doing so, I arrived at a consistent indication of values and norms.

Part II

Empirical work and individual analyses

5. Case Study 1: Opening up myth formation as public sense-making in the context of neuroenhancement

This chapter has been published as: Torgersen, Helge und Daniela Fuchs (2017) Technology assessment as a myth buster: deconstructing myths around emerging technologies. *Journal of Responsible Innovation*, 4(2). Special Issue: Into the wild: Futures and Responsibilities in Technology Assessment p.118-137. https://doi.org/10.1080/23299460.2017.1320157

5.1. Abstract

Responsible Research and Innovation requires the debating of emerging technologies 'upstream'. In discussions on radically novel technologies, comparisons with older technologies are often drawn. This leads to a transfer of assigned properties in the creation of rhetoric so that the new technology appears as a derivative of the older. Sometimes, several comparator technologies are at hand which may give the new technology a different image. Depending on the choices taken in rhetoric creation, a group of actors may acquire advantages over other groups, thereby establishing power relations and sometimes deciding the fate of the technology in question. In this paper, we analyse these processes through a 'hermeneutic' upstream technology assessment (TA) lens, while applying Roland Barthes' concept of myths creation. Using the case examples of synthetic biology and neuro-enhancement, we highlight the importance of the role of comparators and the multilayered character of myths. The potential role of TA as a 'myth buster' may render another task of TA, namely, stimulating a public debate, more difficult because the issue at stake may appear less salient.

KEYWORDS: mythologies, emerging technologies, upstream engagement, comparator, hermeneutic TA

5.2. Introduction

It is often claimed that the 1950s' 'Green Revolution' had saved millions of Indians from starvation due to famine. But has it really? In a conference keynote in 2015, Roger Pielke Jr. explained that the actual famine never occurred (Pielke 2015). Although taken for granted, the Green Revolution's life-saving power was an innovation story grounded in 'more than just the empirical'. Pielke called it a political myth: an untestable but intuitively convincing tale making people believe to support claims *pro futuro*. He adjudged severe real-world consequences to such narratives and demanded technology assessment (TA) to identify and debunk them.

Debates over new technologies have many facets, but in some cases, interests, hopes and fears condense into slogans that may indeed give rise to myths (Hopkins et al. 2007). For example, nuclear fission was said to provide 'power too cheap to meter', nanotechnology to 'build objects atom by atom', synthetic biology (SB) to 'turn biology into true engineering' and cognitive enhancement to 'transgress the limits of human condition'. Dystopic views follow a similar pattern: nuclear power was said to 'poison us' with invisible radiation, nanotechnology to turn the world into 'grey goo', SB to allow mad scientists to 'play God' and cognitive enhancers to turn our children into intoxicated zombies. Once propelled out in the world, myths appear self-evident and compete for the hearts and brains of stakeholders and the public.

In ancient societies, myths have played an important role in explaining the world, but nowadays they seem at odds with an enlightened modernity. Nevertheless, they do not disappear – precisely some aspects of new and emerging technologies (NESTs) seem prone to nurture myths when the stakes are high. The dilemma arising from the lack of available knowledge and the need to influence the trajectory (Collingridge 1980) often tempts stakeholders to make comparisons with previous technologies. Obviously, the precedents invoked and their interpretations differ according to the respective interests regarding feasibility, risks or benefits. Both supporters and opponents claim to base their views on facts, but oftentimes imaginations of futures (whether bright or gloomy) prevail. Consequently, strategic communication involving exuberant promises or serious threats (Kastenhofer 2009) shape the technology's public image.

Of course, this is not a comprehensive picture of all debates about NESTs, but a scenario that scientists, developers and policy-makers fear and that influences how they deal with NESTs (Rip 2006). A possible solution is often seen in 'Responsible Research and Innovation' (RRI), which aims at shaping technological development in a responsible way by involving multiple actors (Owen, Macnaghten, and Stilgoe 2012) at an early stage when the trajectory can still be influenced (Guston and Sarewitz 2002).

To meet Pielke's demand, what can TA contribute if 'facts' are rare? (Grunwald 2013b) proposed that TA could at least assess what is being said through a 'hermeneutic' TA. It could reveal how stakeholders support or oppose an issue and what the underlying values, interests and power relations are, using tools[1] such as vision assessment (Grin and Grunwald 2000) or the analysis of myths (Grunwald 2014). This requires an adequate conceptual understanding; while vision assessment has been elaborated for a TA context, myths remain somewhat enigmatic as an object of analysis. In his talk, Pielke identified three elements of political myths, namely, beliefs, acts and symbols. However, his overall description of myths ('shared stories we tell ourselves that motivate why and how we act in a collective way')[2] does not say much about their characteristics, how they come into life, how they work, what purpose they serve, how we can deconstruct them and what we gain or lose by debunking them.

This article proposes a way to address myths about NESTs in a TA setting, drawing on Roland Barthes's 'Mythologies' (Barthes 1973). We will discuss different meanings associated with the term 'myth' and, with a view to Barthes, explain how TA-relevant myths come into life. SB will provide an example to demonstrate how comparators in expert discourses promote myths. With the example of neuro-enhancement (in the following NE), we will show how public debates mirror expert discourses and highlight the multilayered character of myths. Finally, we will discuss how myth analysis could help assess NESTs and what the 'myth buster' role may entail for TA.

5.3. Myths – more than a nuisance

Pielke's use of the term comes close to an everyday understanding of myths as bundles of unproven stories about enigmatic facts, generalising different versions and expressing them in a way that intuitively makes sense. Myths deliberately distort reality to serve the interests of those who tell them.[3] They spread because they are so catchy, but it is difficult to determine whether people telling them believe in their truth or only pretend to do so. In short, myths are a nuisance to an enlightened society.

In a scholarly understanding building on cultural studies, a myth is much more than a nuisance. Admittedly, it is a historically not verifiable or, by its fantastical character, miraculous narrative. Nevertheless, it creates meaning and provides explanations or interpretations of issues difficult to grasp (Jamme and Matuschek 2014, 12). Even more so, it offers an opportunity to construct coherent self-interpretations and provides clues to social and historical significance (Jamme and Matuschek 2014, 19). In an anthropological perspective, myths explain to a group how something puzzling came into existence and why it is as it is, using images derived from peoples' experiences (Lévi-Strauss 1978/1968). By providing group ownership of meaning, the explanatory power of a myth has an important cultural and political function.[4] These insights were generated studying traditional societies, but they are still relevant today.

By providing genealogical explanations, myths bridge the past, present and future. This both historical and ahistorical structure (Lévi-Strauss 1955, 430) puts myths close to political ideologies. The collection of statements on an issue provides a 'code' or language that integrates norms and facts and creates an immobile world (Brune 2003). Emerging from cultural consensus, myths involve the deliberate suppression of alternative connotative meanings: 'The mythical signification […] is always in part motivated [as] there is no myth without motivated form' (Barthes 1973, 136). This aspect of exclusivity of meaning becomes especially important with regard to dominating a discourse. Myths mostly serve an aim; they influence perceptions or provide a suggestive explanatory basis for decisions that otherwise might be controversial (Blumenberg 2014).

Expanding the meaning of myths from historically decontextualised narratives to contemporary socially operating devices, Bottici and Challand (2006)[5] focus on the social role. Accordingly, myths relieve a distressed individual overcharged with an increasing amount of information by identifying the unknown and reducing complexity: myths render life meaningful because they provide explanations – even if insufficient or illogical upon closer inspection. This makes them attractive, which they need to spread – the process of reception and reproduction guarantees their survival. Bottici and Challand (2006) emphasise that the success of a myth depends on its suggestiveness, even more so than on the relevance for (political) actors.

In their article, Bottici and Challand (2006) explicitly refer to the work of Hans Blumenberg on myths, especially to his argument that in a changing environment, the narrative needs flexibility to stay meaningful for a community. This may explain in part why a myth acquires a life of its own (Barthes 1973): it then becomes independent and spirals out of the control of its originator.

Used intentionally, the explanatory power of a myth, however, may be applied to promote (doubtful) political aims. Under the term 'prefiguration' (Blumenberg 2014), Blumenberg analyses the process of repetition and transfer of meaning from historic events to actual situations to serve a contestable political aim.[6] Such a process involves reference to a seemingly unambiguous past by providing a strong interpretation that is suggested to be consensual. It then transfers this interpretation to an actual case, drawing an intuitive analogy. As a result, the actual case becomes equally unambiguous and consensual. Such an operation provides a strong basis for arguing for and defending decisions and the easy dismissal of counterarguments.

Myths seem to be self-evident, and their role in society is essential because they provide a commonly shared basis of understanding to cope with the unknown. But how

they arise and what makes them so attractive still remain unclear. A social psychological perspective may shed some light on this. The concept of social representation (Moscovici and Duveen 2000)[7] focusses on the analysis of the symbolic 'narrative coping' of lay people as they deal with uncertainty in difficult technological issues, objectification and 'naturalisation' of the unknown (Bauer and Gaskell 1999).[8] Accordingly, people communicate about familiar things in a way characteristic of a group, which provides meaning and group adherence. This way of communication about familiar things is extended to unfamiliar ones to metaphorically 'anchor' and objectify them in order to 'naturalise' them, to make them understandable and interpret them in a group-compatible way. An anchor might not entirely fit, so coping may imply a new reality that, if viewed from an outside perspective, appears distorted. Individuals and groups constantly create representations they adhere to and that help them to understand and form an opinion about unfamiliar issues. This suggests that representations contribute to the formation of myths – if an attractive anchor is provided, one may speculate, a myth can be generated.

5.4. The Barthian mythology

A pragmatic, operational understanding of modern myths around emerging technologies can be found going back to a concept the French (post-)structuralist Roland Barthes developed long ago. In his famous 1957 book 'Mythologies' (Barthes 1973), he departs from the notion of myths being 'a type of speech' (Barthes 1973, 117) that conveys a message. He combined this with Claude Lévi-Strauss's ethnological perspective where myths are '… language, functioning on an especially high level where meaning succeeds practically at "taking off" from the linguistic ground' (Lévi-Strauss 1955, 430f). Thus, Barthes (1973) conceived myths as rooted both within and outside of speech. Not confined to particular media, a myth can be expressed through art, literature, rites or social practices (Bottici and Challand 2006). While anything can take on the role of language in conveying myths, visual representation, for example, photographs, are especially prone.[9] Barthes thus transferred the ideas of (ethnological) myth analysis to the phenomena of everyday culture and 'mythical' occurrences (Brune 2003, 86).

Earlier, Ferdinand de Saussure had characterised speech as linguistic signs attributed to objects to enable communication, highlighting the randomness of the connection between 'reality' and 'sign' (Lévi-Strauss 1955, 429). Saussure's language theory considers a sign to be an amalgam of the signified (a concept or object of a word) and the signifier (a word as the phonetic sequence). For example, if we think of a seagull and associate this concept with the phonetics of the spoken word 'seagull', the result, that is, the sign 'seagull', makes sense and can be understood as a word meaning a bird living by the sea. Barthes took this concept a step further and added a second layer with a similar operation. Thus, a myth is a 'second-order' system where a meaningful sign, the result from a linguistic operation of amalgamating a concept (the signified) and a word (a signifier), itself becomes a signifier for yet another level of connotative meaning (another signified). To stick with our example, the sign 'seagull' becomes a signifier for other objects such as the sea, summer holidays, birds' shrieking, etc.

Barthes suggested that on this second level, an originally meaningful sign is emptied to become a signifier for something else (Barthes 1973, 126-127). The amalgamated result of filling a partially emptied form with this 'something else' is not only a (linguistic) sign. Rather, it is an appellative message carrying a new significance.

However, it still draws from the sign's original meaning – it superficially appears the same – and thus becomes a myth (Figure 1).

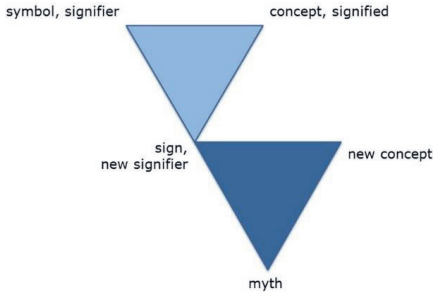

Figure 1: Concept of myth formation according to Barthes

A myth 'parasitises' a sign; it renders it empty and fills it with a new suggestive meaning in a non-transparent way: imagining a seagull, we automatically think of a beach, sunshine and holidays. The meaning of a myth, hence, derives from linking a concrete single incident with a continuous structure. The new significance appears as if the issue necessarily had to be that way from its very nature – a quasi-ontological identity, if only rhetorically created. In other words, a myth assigns intrinsic properties to an issue in a way that intuitively appears logical and natural. It often suggests a particular explanation without offering the slightest factual proof, which appears unnecessary – the mere suggestion is sufficient because it is so convincing. Nevertheless, myths do not lie or hide; rather, they distort or introduce a modification (Barthes 1973, 137), stripping a sign of its historical context.

Apart from rendering the term more operational, Barthes extended the second-order system to a third, fourth, etc., order. This means that a myth itself can become a signifier to be filled with the meaning of yet another signified, giving rise to a new myth, and so on. The result is a chain of consecutive myths deriving from each other. This suggests understanding myths as multilayered systems and invites identifying and analysing previous and potential successive myth-creating operations in the chain. To do so, the respective 'signified' needs to be identified, that is, the concept or object that takes over, colonises the emptied form and renders it a mere signifier. Analysing myths (i.e. being a 'mythologist'), accordingly, demands reading a myth as it appears. Rather than stating that the respective sign is a mere symbol for the signifier, or that both have nothing to do with each other, a mythologist needs to acknowledge and 'consume' its intended message to deconstruct the implicit meaning conveyed.[10]

If we approach the Green Revolution in a Barthian way, a chain of myths emerges: in a first step, 'Green Revolution' as the signifier was associated with the notion of industrialised agriculture. In a second step, the notion of fight against world hunger colonised this 'industrialised' Green Revolution. Years later, the resulting myth-as-a-message was linked to the discourse on agricultural biotechnology – the latter became the signifier, the Green Revolution the signified. This resulted in the message of biotechnology being a further revolution in agriculture necessary to feed the world. Over time, assessments of agricultural biotechnology scrutinised many technological and societal

aspects, while the Green Revolution implicitly or explicitly remained a reference point for both critics and supporters.

One step further, this debate (with its futile supporter/opponent confrontation) again served as a blueprint for conflicts expected to arise over NESTs. Apart from nanotechnology (Rip 2006), especially SB was said to be likely to meet resistance among the public (ETC Group 2007). Empirical investigations showed that SB indeed meets objections similar to those against genetic engineering (Kronberger, Holtz, and Wagner 2012). Public perception of neurotechnologies, too, has been shown to be ambivalent (for a review on attitudes towards cognitive enhancement, see Schelle et al. 2014). These and other hints at public scepticism prompted various administrations to spend much money to educate the public and 'enhance' public debate, hoping to evade further controversies that appeared inescapable.[11]

5.5. Myths in the context of NESTs

With the Green Revolution, Pielke identified a myth in retrospect. In the context of emerging technologies, however, we see myths 'in the making', emerging from hopes, fears, expectations, warnings, polemics, expert opinions, political statements, etc. Different interpretations compete for attention and, ultimately, for discursive dominance, that is, for the power to determine the default view upon a technology that appears obvious. Various approaches have been applied to analyse debates on emerging technologies (e.g. Selin 2008, for systems biology: Döring et al. 2015), in particular, metaphor (e.g. Boon and Moors 2008) and vision analysis (Grin and Grunwald 2000).

Here we may note the relation between metaphors and myths. (Lakoff and Johnsen 2003, 36) described metaphors as '… a way of conceiving of one thing in terms of another, and its primary function is understanding'. Accordingly, it is impossible to avoid metaphors when speaking or thinking. They not only mirror existing similarities between two concepts; in addition, when transferring elements from one area to the other, metaphors create – or distort – reality by hiding or emphasising them. This makes metaphor analysis a technique, complementing myth analysis, for unravelling underlying or unconscious conceptualisations as they manifest in language.[12]

Regarding vision assessment, Grunwald (2014, in the abstract) proposed 'to no longer treat the understanding of the possible meanings of NEST in the RRI debates as a secondary feature, but to put them at the focus of analysis and reflection'. Vision assessment should address and discuss implicit presuppositions in perceptions of new technologies we still know little about. It draws from the old 'leitbild' concept (Dierkes, Hoffmann, and Marz 1992), indicating an effective but implicit guiding principle for technical innovation.[13] A leitbild of an emerging technology (such as the 'paperless office') may contribute to a (deliberately planned) technological future through scenarios, public debates and stakeholder discourses (Grin and Grunwald 2000); it is future-oriented and close to an engineering context.

From an Science and Technology Studies (STS) perspective, the co-production of technologies with and within society manifests itself in the concept of sociotechnical imaginaries (Jasanoff and Kim 2009). They compile ideas, hopes and fears about technologies as part of social life, fuelled by everyday practices, linking the present with an imagined future within a particular, often national, context. Their definition as 'collective imagined forms of social life and social order reflected in the design and

fulfilment of […] scientific and/or technological projects' (Jasanoff and Kim 2009, 120, cited in Jasanoff and Kim 2015, 19) suggests some overlap with myths. However, while we support the contextual focus prominently argued for in STS studies, we explicitly refrain from a national-bound interpretation of technology myths as this is not in line with our empirical findings (see below) – in the context of NE, for example, the assumption of nationally different interpretations of the technology is hardly tenable. Additionally, we understand sociotechnical imaginaries as broader and more encompassing; they provide opportunities to capture narratives beyond the scope of the intentionality of myths and, therefore, reflect a greater variety of emerging technology discourses. Sociotechnical imaginaries provide guidance adapted to a context, indicating future directions that appear intuitively plausible and attractive, but they seem to emerge rather than being deliberately crafted. In contrast, myths on NESTs can arise from intentionally created, persisting narratives that underlie a debate. Hence, myth analysis may be a complement to other methods and perspectives.

What visions, leitbilder or sociotechnical imaginaries have in common is that their attractiveness depends upon their ability to make sense, to provide intuitively attractive meaning and thus to reduce uncertainty in issues that are difficult to grasp; in other words, upon their ability to 'familiarise the unfamiliar'. This function is at the heart of the social representation concept Bauer and Gaskell (1999) applied to the public understanding of NEST, especially to biotechnology. They added a temporal dimension to the concepts of narrative coping with uncertainty, making representation a 'project' where individuals interact in relation to an object over time. To visualise the idea, they devised a series of triangles posed behind each other – the relation of two individuals and an object at a particular point in time, followed by the same arrangement at another point and so on. This 'Toblerone' model[14] depicts the development of a representation over time. A bundle of Toblerone bars, then, indicate different social representations of an issue. While the concept of social representation suggests how myths emerge, the Toblerone model offers a perspective on how they are propagated through communication, and how they change according to the contexts.

5.6. Myth analysis in action

Retrospective reflection and the analysis of myths in politically relevant contexts are, comparatively speaking, rather straightforward. With NESTs, myths are still in the making; thus, it remains unclear which competing narrative will become powerful or disappear. Why should we, and how can we analyse myths that have not yet found their final form? To trace myths 'in the making', we will present two cases of contested innovative fields (SB and NE) aligned to very different narratives. We will first introduce the concept of 'technological comparators' as it manifests in the expert discourse on SB to highlight the aspect of intentionality. With NE we will extend our perspective to public debates and show the effect of 'underlying myths'.

5.6.1. The role of comparators in the mythology of SB

SB attempts to introduce 'true engineering principles' into biology; it sees itself as a constructive discipline that realises the unfulfilled promises genetic engineering made decades ago.[15] In a dominant expert understanding,[16] this implies that, in analogy to electronics, standardised 'biological parts' (DNA sequences) having reproducible properties can be readily combined and introduced into new devices. Parts are mounted

on a 'chassis', that is, installed in an organism deprived of all functions except those necessary for survival, providing the basis for production facilities of hitherto unknown versatility and simplicity. Another interpretation focuses on the role in basic research (de Lorenzo and Danchin 2008). Following Richard Feynman's saying of 'what I cannot create, I do not understand',[17] SB provides tools for analysing the basic functions of life by building new life forms bottom-up, yielding insights inaccessible so far (Rasmussen 2010). Although practical benefits are expected, the industrial aspect is not at the fore in this line of reasoning.

In both cases, SB draws analogies to information technology with the carrier of information being DNA instead of electrons (Heinemann and Panke 2006). This comparison is both suggestive and promising because it renders difficult facts and procedures easily understandable. At the same time, it suggests a bright future, much like that information technology had in retrospect at a similar point in development (in the early 1970s). Multiple analogies have been brought forward, from SB 'garage shops' looming to the predicted ubiquitous presence of the technology some decades into the future. To illustrate this comparison, Andrianantoandro et al. (2006) mounted the different information hierarchies in SB and in computer sciences side by side in a suggestive way. The message is obvious: SB not only *is like*, but also *is* a kind of information technology and its future will be equally bright.

A totally different picture emerges from the cover of an early NGO report (ETC Group 2007, Figure 2). The 'Action Group on Erosion, Technology and Concentration' (ETC Group) had engaged in the struggle against agricultural biotechnology and was among the first to raise critique at SB. The cover picture showed a paraphrase of Michelangelo's famous Sistine Chapel painting of Man's creation, depicting God admonishing Man not to play with a DNA molecule made of Lego bricks. It played with several motifs: the Lego analogy scientists kept highlighting, the DNA molecule as a symbol of life and the suggestion that God was not amused over Man playing God using Lego bricks. The report's title 'Extreme Genetic Engineering' explicitly suggested the comparison. It alluded to the allegation of scientific hubris brought forward in past debates over eugenics, agricultural biotechnology and risk. By implicit reference, the cover suggested that much like genetic engineering, SB was doomed to fail due to its inherent hubris, which would entail excessive public controversies.

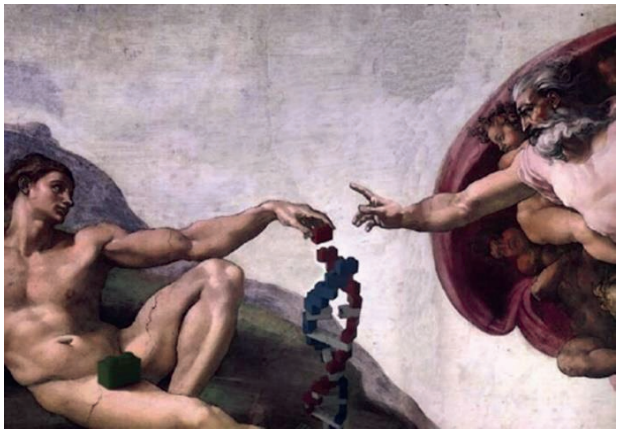

Figure 2: The ETC group's depiction of SB.
Source: By courtesy of ETC Group (2007) (http://www.etcgroup.org/)

Information technology and genetic engineering suggest two entirely different stories without providing evidence for any of them (Bogner and Torgersen 2015). How would they appear in a Barthian view? (Döring and Torgersen 2012). Let us conceive 'SB' as the signifier, that is, a word to be filled with something signified, a concept or object. Let us say the signifier 'SB' is empty and gains meaning from the signified. The signified may consist of different objects; often it is derived from (or is) a comparator that is put in the place of the object. If the signified is 'genetic engineering', SB no longer is considered 'like' it, but rhetorically acquires particular properties – SB semantically turns into genetic engineering in a 2.0 version. This is because the signifier 'SB' is not empty but still carries meaning, if only that of a powerful new technology. In contrast, if the signified is 'information technology' and exceeds the 'as if' character, SB turns into an information technology with a biological information carrier (DNA). Rhetorically, the known properties of information technology are conveyed to SB. In the end, the amalgam is totally different in each case – a menacing extension of genetic engineering prone to raise endless debates and inviting mad scientists to play God, or a novel information technology in its infancy with a bright future that will become pervasive.

This operation of assigning meaning from something with a disputable relationship to the term SB is not made explicit, and the result, the 'sign' in the language of Barthes, becomes a myth. The term myth is thus being defined as the result of the implicit assignment of a new borrowed meaning to a term, keeping intact some of its previous content but filling it with the character of the source of the borrowed meaning. It assigns new and seemingly intrinsic properties to the issue the signifier stood for in the beginning; it 'naturalises' the issue in terms of the signified. In the end, it appears as if the issue ontologically is as depicted, that SB, by its very nature, is genetic engineering version 2.0 or information technology with a new carrier, respectively.

Meaning is conveyed by genetic engineering and information technology as 'comparators' for SB (Torgersen and Schmidt 2013). The public make sense of the respective established technology because they already have heard about it or have encountered its products. SB, new and unknown, is said to be like the older one, respectively, emphasising a set of characteristics and attributes that appear easily transferable. Beyond technical details, people get an idea of what SB is like, what it might

be used for and where the associated pros and cons are. Similarities and differences between old and new are not systematically compared; rather, the older technology provides a gross orientation, assigning a certain 'nature' – characteristic and seemingly intrinsic properties – to the new one. In the end, the latter is considered literally akin to the older in almost every respect, except those that deliberately make up the 'novelty'. The new technology no longer 'is like' the older; rather, it is rhetorically transformed into a variety of the older. The image of the older technology determines or at least strongly influences the perception and discursively 'colonises' the new one.[18]

In popular scientific debates, comparators often set the frame, enabling people to speak about the new technology (Bogner and Torgersen 2015). At the same time, ideas about technological concepts distorted through mere transfer give rise to myths that are held to be true without further evidence. Myths benefit certain actors and harm the interests of others; this can be exploited: if the 'signified' can be almost any object, an interested actor may conceptually link to a new technology whatever he or she wants in order to pursue a particular aim – for example, to elicit certain associations or emotions with a target group or the general public.

In the context of SB, we see competing myths propagated by different stakeholders. This suggests intentionality – an object is deliberately put in the place of the signified not by chance, but by an actor with an interest. Critics want to make people believe that SB is genetic engineering version 2.0; and engineers pushing the issue suggest that SB is akin to what they always have been doing. Actors compete in promoting their interpretation to create a dominant myth that will determine the future of the technology and the distribution of risks and benefits. As long as myths are still in the making, it is not clear which one will be dominant in the end. Once settled, it may be difficult to overturn the narrative as it will appear self-evident.

5.6.2. Myths in the making: NE

In a debate about NESTs, elements of meaning flow in from many previous debates. Issues are not yet settled and uncertainty about who might benefit from a particular interpretation prevails. In such a case, we may directly observe the formation of a 'second-order' myth: an issue gets linked to an existing 'underlying' myth. For this process, a look at the expert debate around a technology with an unclear profile is helpful.

NE aims at improving the performance of the human brain. This can pertain to attention, cognition, memory, creativity or other abilities (Hildt and Franke 2013). Means may be drinking coffee (ingesting caffeine), taking prescription or illegal drugs such as methyl-phenidate (Ritalin) or amphetamine, or applying trans-cranial magnetic or constant current stimulation (Nuffield Council On Bioethics 2013). Existing social practices use old methods of low efficacy; new experimental technologies are unlikely to become popular soon (Hildt and Franke 2013). Nevertheless, from time to time the media try to raise interest by reporting that new powerful methods are imminent.

Promises respond to individual wishes for boosting brain performance to cope with the increasing demands in a competitive society (Grunwald 2013a). A different motive comes from a trans-humanist agenda – to sketch out new ways of overcoming human limitations and thus extending the *conditio humana* (Savulescu and Bostrom 2009). Another motive is linked to innovative playfulness as trans-cranial stimulation has become popular among young 'brain hackers'. Devices are sold over the Internet to the gaming community, promising improved performance and conveying a taste of coolness (NERRI 2016).

Thus, NE appears multifacetted: practices span from everyday habits to criminal offences, means from established drugs to experimental treatments, and intentions from acquiring a positional good to science-fiction-inspired ideology – different meanings may be attributed to the idea of enhancement and appear self-evident (Ferrari, Coenen, and Grunwald 2012). While the trans-humanist approach is expert-driven, 'brain hacking' emerges from a lay perspective. Many parallel discourses apply the term NE differently. There is no dominant interpretation of what NE 'is' and what it serves to; rather, groups of experts or lay people with particular interests assign various meanings to it.

The sources of meaning are diverse. Trans-humanists take up ideas from science fiction such as locating human consciousness in a data cloud or technically extending the human lifespan.[19] Other sources relate to health, such as NE as applied to save lives or restore normal function, which implies questions of risk and safety. In interviews, medical experts criticised the blurring distinction between therapy and enhancement, which they compared to developments such as doping in sports and aesthetic surgery (Sauter et al. 2015, NERRI 2016). This throws up the question of misuse and personal freedom, of what is normal and 'natural'. NE, accordingly, might assign advantages to individuals unfairly, blurring the distinction between genuine skills and artificially acquired performance. Other experts focussed on societal aspects, speculating that the wish for NE may result from not being able to cope with an increasingly competitive society. In fact, society may become over-competitive through its widespread use.

All this is not confined to NE but is derived from other discourses, such as on doping, recreational drug use or competition in late capitalism. Motives and thought patterns are borrowed in order to assign meaning to NE through implicit comparisons, suggesting ways to handle the ambivalent subject. When expert and policy-makers' views reach public debates, aspects become aligned with individual perspectives. Elements of meaning are picked from previous debates, assigned to NE and the results compete for interpretative dominance.

An example is the myth-generating power of lay initiatives such as brainhacking. Similar to the biohacker movement in SB, it derives its meaning from practices in information technology (which the designation 'hacker' refers to). In SB, the notion of coolness, non-conformism, joy and potential economic reward goes along with the 'hacker' image (Torgersen and Schmidt 2013). Irrespective of the technology, the do-it-yourself approach emphasises self-determination and the freedom of experimenting with one's own body in complete autonomy. Tinkering with NE is a means to live out this autonomy, engaging in competitions using self-built devices.

Alternative comparisons lead to entirely different images of NE. In expert workshops and focus groups[20] with teachers and students, some participants compared NE having coffee, an everyday practice, to forbidden doping using amphetamine. Others emphasised the consequences of an over-competitive society; comparisons were made to cosmetic surgery blurring the boundary between therapy and enhancement or to cheating in the classroom as a morally doubtful but widespread practice. In these stories, NE was either 'like' another practice such as cosmetic surgery, or 'akin' to something else, that is, doping. In *bona fide* comparisons, one issue was juxtaposed to the other; in naturalisations, the rhetoric creation of a quasi-ontological identity entailed a transfer of seemingly intrinsic properties from the comparator to the issue at stake.

With myths in the making, the comparator slowly takes over. To use a Barthian language: initially, the sign remains 'full', but slowly gets colonised by the new signified. Depending on the comparator, the implicit acceptability differed widely and proposed different moral consequences and measures (Figure 3).

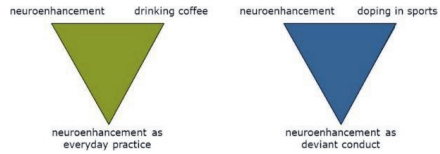

Figure 3: Alternative myths on NE

Despite differences, almost all focus groups raised the issue of competition. The perceived need to react to the real (or presumed) pressure to perform better was a leitmotif of the debates. This common predicament appeared irrespective of the technical means and their acceptability. Consequently, NE was rejected not because of perceived risks or drawbacks of a particular technique, but because participants felt a pressure to perform better and bear all the costs, while the benefit would go to those who exert the pressure; in other words, they felt exploited. In a Barthian perspective: a sign, cognitive performance, is turned into a signifier and gets colonised by a new signified, competition, giving rise to the new myth of cognitive performance irreducibly linked to competition – a chain of myths emerges (Figure 4).

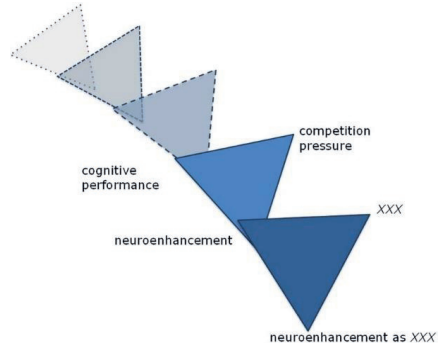

Figure 4: The myth chain as part of a network

Tracing the chain back, the idea of social pressure to enhance performance has its roots in developments said to challenge present living conditions, such as the competitive knowledge society, the global productivity race, etc. The underlying myth of competitiveness might be fuelled by fears of competition defined as a value in itself, of meeting one's 'natural' performance limits, of losing edge to those still at bay but becoming superior, etc. However, the seemingly inescapable solution, NE by technological means, appears as 'sheer madness', as a participant put it, because the underlying ideas are perceived as mad. The notion of pressure from competition (as the 'signified') may itself be the result of a myth-generating process. Further analysis might render the chain into a network of myths, where both the signifier and the signified are derived from myth-generating processes.

Taken together, the images of established practices or older technologies determine the perception of the new one; they discursively 'colonise' it, giving rise to potential myths. The new technology no longer 'is like' the older; rather, it is rhetorically transformed into a variety of the older. In an everyday setting, myths as (partly) decontextualised narratives can be linked into chains, handing meaning from one myth to the other, creating networks of myths whose elements may derive from debates long gone. Such a chain of myths can indicate long-standing power relations, benefiting some actors and hindering others from pursuing their interests. A dominant myth may thus influence or even decide the discursive or political fate of a technology to come in a distant future.

5.7. TA – more than a myth buster?

Sense making by transferring meaning and linking previously unconnected issues is a universal process that allows individuals and groups to cope with the unfamiliar such as NESTs. Linking may be deliberate or, at least, supported to influence the debate and, subsequently, to shape the image of an issue. Myths, therefore, are an inevitable part of any debate on a new technology. What does this entail for TA – should debunking myths be a genuine function, and what is the analytical and practical value of such an endeavour?

TA has been assigned with different tasks that may be summarised under an analytic and an interactive perspective (van Eijndhoven 1997). In its beginnings during the 1970s, TA was a mainly analytic endeavour to provide Parliament (the US Congress) with independent technical expertise on technological issues with potential financial, economic, environmental, health or social impacts, so that Members no longer had to depend on partisan information.[21] Early warning of unintended consequences from novel technologies also became a major issue. Debunking myths was an essential part in this analytic activity as the aim was to arrive at an 'objective' assessment using the best factual evidence available.

Later in Europe, forms of TA developed 'in which the analytic product became of relatively minor importance compared to the interactive process' (van Eijndhoven 1997). Involving the public through participative formats, such as the consensus conference, aimed at including lay expertise and independent non-expert views into a 'public TA' to provide a more comprehensive collection of stances and to prevent expert views (and interests) from dominating (Joss and Durant 1995). Like previous forms, public TA should inform policy-makers to enable them to shape technologies along the lines of the public good, preventing the dominance of partisan interests. In contrast, constructive TA (Schot and Rip 1997) was devised to influence design practices by bringing stakeholder and user perspectives into the actual construction work with the aim to arrive at 'socially robust' technology (Nowotny, Scott, and Gibbons 2001). Debunking myths was not at the fore here.

More recently in the context of RRI, key concepts such as the co-responsibility of actors and the responsiveness of research and innovation agendas to societal requirements experienced an upswing. Clarifying societal needs requires the participation of stakeholders and the broader public in technology development (von Schomberg 2012). With emerging technologies, real-time or 'upstream' assessments incorporate the views of stakeholders and the public at an early point to influence developments in a rational way (Guston and Sarewitz 2002). Compared to older modes of TA, upstream assessment of emerging technologies requires organising participatory activities tailored to the respective demand, which has become a core task for TA.

'Upstream' TA should identify potential futures as they emerge from the visions and imaginaries of stakeholders, experts and members of the public. Probably, these futures will not materialise at any point in time; rather, they indicate existing preferences in present society (Lösch 2006). This is an analytic task that requires, to some degree, a debunking function not least because these futures exert power through framing and guiding wishes and thoughts. Apart from identifying and describing visions, TA needs to contribute to the understanding of where they are derived from, what lies behind them, what they imply and how they might develop in future. The myth concept comes in handy here. In addition, the TA field always had the pretension of identifying and deconstructing hidden power relations that influence the distribution of risks and benefits from novel technologies. Beyond 'establishing the facts', analysing who might have an interest in shaping and propagating myths may help to identify power relations and enable disadvantaged actors.

However, there is a caveat: TA approaches themselves might unwillingly contribute to the creation of myths. By definition, an emerging technology is unknown and disconnected from peoples' everyday worlds, so an 'upstream' public or stakeholder debate is always held on an ambiguous and uncertain ground. It is necessary to convey to the participants an adequate picture of the technology and its context in the discussions. It must be sketched out in a way understandable to lay people; in addition, its relevance needs to be emphasised to make stakeholders and the public engage. This is usually done via comparators and analogies to more familiar technologies and applications (Bogner and Torgersen 2015) – a necessary step but inevitably, particular aspects may be hyped or neglected. In other words, a process of myth generation might be activated. Providing a stage in participatory events then might result in placing one myth against the other without coming to a conclusion. As the media logic primarily goes for salience, myth generation is especially imminent if the engagement process and its results gain media attention. While coverage is an asset in times of impact measurement, it may complicate the task of TA to perform a 'reality check' on emerging technologies. Being a myth buster and saying that the emperor is naked, however, do not really help in promoting a discussion. Nevertheless, TA must diligently control for any attempt at 'emptying' the original sign. This implies procedural provisions, such as, for example, making sure that comparators are identified as such and that the similarities and differences between the comparators and the technology to be explained are clearly stated. Otherwise, the process of upstream engagement carries the risk of (re-)producing or promoting myths that might become dominant. The double task of upstream TA – stimulating a debate while unmasking unwarranted claims – remains a tightrope walk.

There is a more fundamental problem in the debunking of myths deriving from the insight that they cannot be avoided. Myths have an essential function for understanding difficult and unfamiliar issues, for providing meaning and addressing uncertainty, and also for group coherence. If factual information is scarce, a debate will inevitably bring up myths. The analytic task of TA demands debunking them, but the myth buster activity needs to be accompanied by more constructive approaches, providing new perspectives to combat normative uncertainty. Such a combination could show a way towards an 'enlightened mythology' that identifies and analyses myths as they appear in the debates over the roll-out of NESTs, and, at the same time, provide sober orientation that may help to create new innovative and coherent sociotechnical imaginaries.

Candidates for constructive approaches may be found in interdisciplinary activities aimed at sociotechnical collaboration to support Responsible Innovation (for a review, see Fisher et al. 2015). Such collaboration focuses on the 'relation of expert practices to their (often segregated) social context, operates in close proximity to the expert practices in question, and functions to catalyse or support transformation of those practices in their societal context' (Fisher et al. 2015, 41). Various approaches have been tried, and although they have been criticised in terms of potential capture or lack of outcome (see Chapter 2.4 in Fisher et al. 2015), many scholars consider some form of sociotechnical collaborations a necessary prerequisite for Responsible Innovation. In combination with myth analysis and myth busting, collaborations could give rise to a form of 'midstream' (Fisher, Majahan, and Mitcham 2006) TA, particularly in the modes of 'problematising' and 'reforming' science and innovation, where alternative values may gain ground.

The Citizens' Visions on Science, Technology and Innovation (CIVISTI) process (Gudowsky and Sotoudeh 2017) can be considered a form of organising sociotechnical collaboration and, at the same time, providing an arena for myth identification and deconstruction. It was originally developed with the aim to identify European citizens' visions of the future and transform these into relevant long-term science, technology and innovation issues for the EU research and development (R&D) policy. Although consulting citizens is by no means new, the process was novel as it combined the sequential generation of visions by lay expertise and the checking by expert assessments, leaving the final word with the citizens. On the one hand, it tries to avoid the dominance of expert views and interests and, on the other, to keep popular projections from becoming unrealistic. Both hidden expert interests and unwarranted popular projections had been important sources of myths in the past. Through double-checking the results of each step by different forms of expertise and subjecting them to alternative views, the process aimed at a clear expression of desired futures and went some way in showing how they could be pursued.

5.8. Conclusion

Departing from Roger Pielke's notion that society wades in a flood of (political) myths when it comes to sociotechnical innovation, we tried to show that myths are not only a nuisance, but can also yield a valuable resource for TA. At the same time, the analytical part of the TA agenda suggests that identifying and debunking myths (as far as possible) are necessary steps. Otherwise, they would distort the results of the TA process and render a skewed picture of the issue at stake. For both, understanding and debunking myths, we propose an approach informed by Roland Barthes' classic conceptualisation, which may be adapted and, if necessary, simplified to suit the needs of TA. We think that understanding how myths come into life, how they work and what purpose they might serve facilitates their deconstruction and provides a clearer view on the issue at stake and its sociotechnical context.

This said, it is clear that we never will get rid of myths as they are a prerequisite for the appropriation of difficult or unfamiliar issues – such as novel technologies and their implications. Furthermore, identifying a myth does not necessarily abolish its power. However, (hypothetically) stripping an issue from all myths attached would render it 'naked', difficult to understand and to come to terms with. Therefore, new imaginaries

need to be constructed around the issue through preferentially open-ended, theoretically informed and methodologically controlled sociotechnical collaborations.

The next steps would be to devise a consistent methodology for myth analysis, using appropriate examples of technological innovation. This should be combined with processes to construct novel imaginaries on foundations that are no longer hidden, but explicitly refer to the preferences and ideas of a variety of stakeholders, experts and other citizens. Apart from issues of technological innovation, such a process might even be amenable to other areas of the public sphere that are prone to be myth-ridden.

5.9. Notes

1. Both vision assessment and myth analysis build on elements of discourse analysis, but are pragmatic approaches that cannot claim its scientific rigour, which would be unfeasible in a TA context.
2. http://slideslive.com/38893099/technology-assessment-as-political-myth at 3:06.
3. For example, Hopkins et al. (2007) found no empirical evidence for the so-called biotech revolution, which allegedly had changed the pharmaceutical sector. It only existed in the promotions of academics and consultants.
4. This, according to Lévi-Strauss (1978/1968), is how religious orthodoxy is maintained.
5. Insights derived from deconstructing the slogan of the 'clash of civilisations'.
6. The example was Hitler's recourse to the medieval Stauffer Emperor Friedrich II.
7. Already in the 1960s, Serge Moscovici coined the term in his ground-breaking work on the understanding of psychoanalysis in French society. The theory was then extended and applied to analyse everyday discourse (Wagner and Hayes 2005).
8. The concept may also be seen in the light of Blumenberg's notion of prefiguration, where an issue is conveyed to a new or unknown issue, bridging the past and the present.
9. The example Barthes (1973) used in the explication of his theory was a mid-fifties cover of the journal 'Paris Match' displaying a young African in a French uniform saluting (to the Tricolore?). Amidst the Algerian war, it conveyed a suggestive message about French imperialism being accepted by those exposed to it.
10. This seems to contradict the role of an analyst being detached from his object. Barthes' own consideration of this relation was ambivalent (Körte and Reulecke 2014, 19).
11. Although unfounded, decision-makers perceived the myth of 'nanotechnology-phobia' (Rip 2006) as a serious threat.
12. For TA, however, a full metaphor analysis would be very time-consuming (see Maasen 2000).
13. For leitbild assessment, however, mostly in retrospect, see Dierkes, Hoffmann, and Marz (1992).
14. The 'Toblerone' model received its name because its shape reminds of the famous Swiss chocolate bar.
15. Synthetic Biology Community website, http://syntheticbiology.org/.
16. International Genetically Engineered Machine (iGEM) Foundation website, http://igem.org/.
17. Allegedly derived from Feynman's last blackboard: http://archives.caltech.edu/pictures/1.10-29.jpg.
18. This function reminds of Blumenberg's (2014) concept of 'prefiguration', only that in his case a historic person (the Emperor Friedrich II) served as the comparator.

19. For example, Silicon Valley tycoon Peter Thiel's Breakout Labs initiative (https://www.washingtonpost.com/business/on-leadership/peter-thiels-life-goal-to-extend-our-time-on-this-earth/2015/04/03/b7a1779c-4814-11e4-891d-713f052086a0_story.html).
20. Expert workshops and focus groups were conducted as part of the FP7 project NERRI (03/2013 to 05/2016), which aimed at fostering the deliberation on NE between different societal actors. The NERRI consortium (18 partners in 11 countries) organised over 60 events throughout Europe as part of the Mobilisation and Mutual Learning Action Plan. An overview can be found on the project homepage (www.nerri.eu).

In Vienna, two workshops with experts from different professions (from military to physiology, selected through exploratory interviews) and four focus groups were held in 2014/2015. Focus group participants were selected on the following considerations: (i) as non-medical NE is said to create trade-offs between performance and social behaviour, a professional context where both aspects play a role was important; (ii) teachers in their daily life meet stressful situations and might consider using NE; (iii) teenagers are suspected to be more open-minded and likely to try out NE. In the end, focus groups were held with two groups of high-school teachers (approximately 10 each) and two groups of high-school students (classes of approximately 20, 16/17 years) in two different school types (business and integration) in Vienna. Information input was based on results of a literature review and explorative interviews with school personnel; the discussions covered questions of regulation, assessment, risks and ethics. Discussions were transcribed and analysed via qualitative content analysis.
21. Mostly in the USA, this also included involving stakeholders.

5.10. Additional information

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6. Case Study 2: Opening up the engagement of civil society organizations in dialogues on synthetic biology

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6.1. Abstract

Responsible Research and Innovation calls for comprehensive public and stakeholder involvement. Its specific requirements, however, have raised criticism concerning the limitation of engagement opportunities for actors like Civil Society Organizations that do not share mainstream perspectives on technological innovations. Our article investigates the engagement of critical Civil Society Organizations in public debates and dialogues on synthetic biology and asks how they contribute to opening up respective debates. Based on three case studies, we show how Civil Society Organizations engage in and frame the debate on synthetic biology in different organizational formats. We find that Civil Society Organizations have explicitly challenged visions of a sustainable future by airing concerns about its risks and adverse impacts and engage in ontological debates about synthetic biology. Yet, we argue that different engagement formats are needed to ensure a diverse public debate on synthetic biology.

Keywords: civil society organizations, framing, responsible research and innovation, societal engagement, synthetic biology.

6.2. Introduction

For the last decade, the concept of Responsible Research and Innovation (RRI) has entered policy and academic debates, particularly in Europe, to ensure research and innovation (R&I) in a responsible way. RRI aims at reconciling the economic imperative of innovation with societal needs, concerns, and expectations (Owen et al. 2013, von Schomberg 2013, von Schomberg and Blok 2019). Accordingly, new procedural demands for R&I, such as anticipation, reflexivity, inclusion, and responsiveness, have been developed (Stilgoe, Owen, and Macnaghten 2013). More concretely, the European Commission defined pillars of responsibility, such as public engagement, open access, gender, ethics, science education and, eventually, institutional change. In all RRI frameworks, societal engagement is key to R&I activities and governance (among others, see Kuhlmann et al. 2016, Owen et al. 2013, Stilgoe, Owen, and Macnaghten 2013). It calls for including various societal actors in deliberations on the purposes, designs, risks, benefits, and ethics of new technologies (Burget, Bardone, and Pedaste 2017, Kuhlmann et al. 2016, Stilgoe, Owen, and Macnaghten 2013, Wickson and Carew 2014). RRI particularly aims at engaging societal actors previously underrepresented in R&I, namely Civil Society Organizations (CSOs), such as environmental, consumer, religious, youth and patient organizations (Rask et al. 2016), and unorganized publics, such as citizens (Bauer, Bogner, and Fuchs 2021).

The emerging technoscience synthetic biology has become a prime application area for RRI. From the early 2000s onward, synthetic biology has been of increasing interest to scientific and policy communities. It encompasses activities and techniques focused on the design and construction of new biological parts, devices, and systems, or the redesign of

existing natural biological systems for specific purposes (Endy 2005). Potential application areas range from medicine to energy generation or food production, including developments like the recent COVID-19 vaccines based on mRNA techniques (Dolgin 2020) or microalgae-based renewable energy (Jagadevan et al. 2018).

Accordingly, synthetic biology is expected to contribute to economic competitiveness, to tackle societal challenges, and to foster sustainable development. Yet, it has also been characterized as a breeding ground for profound public controversies (Asveld and Stemerding 2016, 2017), similar to agri-biotechnology in the 1990s. Back then, technology-critical voices, among them CSOs, initiated and fueled public protests across Europe, which eventually resulted in regulatory initiatives on the use of genetically modified organisms (e.g. labeling of agricultural products, strict regulations for farming, the ban of cultivation) and rejections by consumers in several countries. Based on these experiences, industrial and policy actors have come to perceive the public as a potential threat to technological progress, innovation, and competitiveness (Hess 2015, Welsh and Wynne 2013).

Simultaneously, it became clear that R&I ran the risk of bypassing (or even contradicting) societal wishes, needs, and concerns. In RRI, exploring a range of epistemic and normative positions, that is, opening up the debate before decision-making, is key to enhance legitimacy and transparency (see, e.g. Stirling 2008). Here, CSOs are usually assumed to represent perspectives and values of a wider society (Krabbenborg and Mulder 2015), to be willing to engage in a (rational) debate on new technologies (de Saille 2015, Krabbenborg 2013), and to adopt a "balanced view" (Von Schomberg, 2013). Yet, these assigned functions of CSOs have been problematized (see e.g. Ahrweiler et al. 2019). With synthetic biology as a showcase of governing an emerging technoscience under RRI, we currently lack a deeper understanding of how CSOs engage in public debates on synthetic biology. How do CSOs contribute to opening up (or closing down) public debates and dialogues on synthetic biology, under RRI and beyond?

To answer this question, we first discuss the literature on social movements and CSOs in technology governance to derive key dimensions for our empirical analysis of opening and closing processes (section 2 [section 6.3 of the thesis]). Based on three case studies of controversies and dialogues on synthetic biology (section 3 [section 6.4 of the thesis]), we then describe the role of CSOs in opening up the debate at different levels, through different participatory processes with special attention to the aspect of problem framing (section 4 [section 6.5 of the thesis]). In section 5 [section 6.6 of the thesis], we discuss the potential and challenges of CSO involvement in opening up the debate by comparing our cases. Finally, we draw conclusion for science, technology, and innovation (STI) governance under the framework of RRI (section 6 [section 6.7 of the thesis]).

6.3. Civil Society Organizations in science and technology controversies

Historically, social movements and CSOs have molded public STI debates by advocating specific societal perspectives. Consequently, their engagement steered broad interest among the social sciences: controversy studies focused on technology-centered activism and protests (e.g. on nuclear energy or gene technology) which led to a rise of CSOs in many countries (cf. the founding initiatives of Greenpeace or Friends of the Earth International). Social movement research studied the framing activities and effects of social movements in public discourses (e.g. Benford and Snow 2000, Snow et al. 1986).

Science and Technology Studies scholars highlighted their contributions to the "democratization" of science and technology (Breyman et al. 2017, Callon and Rabeharisoa 2003, Epstein 1996a, Irwin 1995, Wynne 1992). With the rise of RRI, the interest in CSOs has gained further momentum regarding how to formally involve CSOs in STI governance (see e.g. Levidow and Neubauer 2014) and their role(s) in R&I (Ahrweiler et al. 2019).

In RRI, considering diverse perspectives through (public) participation allows to weigh several epistemic and normative positions before decision-making. This "opening up," that is, sustaining a broad range of perspectives (Stirling 2008), ensures transparent and legitimate decision-making and thus, more democratic governance arrangements for synthetic biology (Stirling, Hayes, and Delborne 2018). Notably, "opening up" does not concern actor involvement only but how their perspectives are sustained throughout a debate or process, that is, whether the full range of perspectives is considered before a decision is made. In this article, we focus on CSOs' engagement to gain insights in how they contribute to opening up and closing down of debates on synthetic biology. We operationalize "opening up" in relation to three analytical dimensions, namely (1) engaged actors, (2) participation formats, and (3) problem framing.

First, to account for the plurality of perspectives, we look at who is participating and the roles acquired by CSOs in each setting. In general, actor roles are situated "in between" the individual and society, drawing attention to issues of power, politics, and agency (e.g. in transition toward sustainability, see Wittmayer et al. 2017, 47), and establish "a shared reality to which actors can refer," linking individual actors to cultural regularities (Wittmayer et al. 2017, 49, cf. Lynch 2007). Hence, actor roles are negotiable and must be accepted by all actors to become meaningful. CSOs often take on the role of formulating societal discomfort and concerns about individual and collective risks, environmental impacts, and social justice related to emerging technologies (Llorente, Revuelta, and Carrió 2021). They do so by initiating public actions and demonstrations, legal interventions, and political engagement (Mejlgaard et al. 2012). Moreover, CSOs mobilize and challenge scientific knowledge claims by pointing to the areas of undone science (Hess 2016), and call for broader societal engagement in (and critical reflection of) STI governance (Miller and Scrinis 2010). Accordingly, CSOs have been conceptualized heterogeneously, for example, according to their missions, objectives, and ways of engaging with society (Ahrweiler et al. 2019, Rainey, Wakunuma, and Stahl 2017, Hess 2015, Nugroho 2011). In research, CSOs have engaged in producing data and knowledge, deliberating on research and risk assessment, and campaigning for transformative knowledge (Göbel, Ottolini, and Schulze 2021). In RRI research projects, CSOs also provide access to networks (Ahrweiler et al. 2019). Regardless of these diverse roles, visions of the European Commission largely conceptualize CSOs homogenously as representatives of a societal perspective (Ahrweiler et al. 2019). This overlooks the manifold motives, activities, and roles of CSOs in R&I processes, and conceals their active role in issue framing.

Second, organizational formats with their specific conditions shape how participation is conducted. RRI has emphasized a shift in societal engagement formats from uninvited (e.g. protests) toward invited, organized engagement (such as panel discussions, stakeholder workshops, or involvement in research projects, see Bauer, Bogner, and Fuchs 2021). This affects how actors (including CSOs) engage in STI debates, regarding the intensity and modes of interaction, and their power and control. Uninvited

engagement is characterized by a common interest of CSOs, openness regarding the number and composition of people involved, self-selection of participants, and no *a priori* time limitation of engagement (Bauer, Bogner, and Fuchs 2016). Invited engagement is organized by participation experts—often project-based with a set number of participants, timeframe, process structure, and issue framing (Bauer, Bogner, and Fuchs 2021). Benefits of such organized processes for STI governance are their high predictability, controllability, and facilitation of structured conversations that ensure particular requirements (Bogner 2012b). Due to its preselection of participants, invited engagement tends to favor CSOs "with hierarchical management structures, funding streams, and spokespeople versed in the rules of elite political engagement" over less formal actors, such as grassroots movements (de Saille 2015, 102). Consequently, scholars criticize that invited engagement fostered by RRI does not consider diverse perspectives equally (de Saille 2015, Welsh and Wynne 2013). In addition, emphasis on invited engagement may affect the perception of uninvited participation: involving "the public" in technoscientific decision-making and increasing state control of "uninvited publics" seem to align (de Saille 2015, 103, cf. Welsh and Wynne 2013, 541).

Third, CSOs do not carry an externally given societal perspective but actively engage in producing and maintaining meaning (Benford and Snow 2000, Snow and Benford 1988). Such frames serve as interpretative schemes which help to understand and problematize the technology at stake and to mobilize consensus and action (Benford and Snow 2000, Klandermans 1984). CSOs engage by reframing, counterframing, or adversarial framing of issues which may result in "framing contests" with established actors of STI (Benford and Snow 2000). Invited engagement may restrict this tendency: even if impartiality and balance are pursued, it is easily framed to align with the interests of specific actors (Landeweerd et al. 2015, 14). CSOs may easily consider the debate "closed down," if its framing is predetermined by incumbent interests (Bauer and Bogner 2020, Chilvers and Longhurst 2016). Hence, a systematic favoring of invited engagement risks to neglect alternative framings (Sykes and Macnaghten 2013, 100), such as justice, welfare standards for marginalized groups, or politics of exclusion (Bauer, Bogner, and Fuchs 2021, Landeweerd et al. 2015). Moreover, framing affects how actors (including CSOs) get enrolled, their willingness and opportunities to participate, and their own (framing) power (Bauer, Bogner, and Fuchs 2021). Thus, whether and how framings are opened to scrutiny affects the tendency to "open up" or "close down" debates on synthetic biology.

As "opening up" or "closing down" cannot be defined in absolute terms, we first conceptualize "opening up" as engaging a broad(er) range of actors or framings, compared to the respective initial situation. Taking this as a starting point, we analyze actors' tendencies to exchange or reframe arguments to indicate the quality of "opening up" or "closing down," and acknowledge that they relate to "outcomes, processes, purposes" and "expectations/visions/imaginaries" (Urueña, Rodríguez, and Ibarra 2021, 5). More specifically, they designate the "amplitude of space for alternative 'plausible' and/ or 'desirable' futures" (Urueña, Rodríguez, and Ibarra 2021, 6). They do so by (de)constructing potential future pathways of technosciences, such as synthetic biology, and their societal embedding, considering heterogeneous constraints, including technical, methodological, axiological, or epistemic ones, among others (Urueña 2019, Urueña, Rodríguez, and Ibarra 2021, 6). Most importantly, we do not understand these constraints as immutable, but rather emerging and dynamic, as they are "explicitly or implicitly

established and/or co-negotiated during the whole process" (Urueña 2019, Urueña, Rodríguez, and Ibarra 2021, 6).

Thus, in this article, we look at how CSOs are enrolled and particularly, how potentially "unruly" CSOs participate in debates on synthetic biology. To illustrate the wide array of CSOs activities, we investigate diverse, yet partly connected, engagement settings, including invited and uninvited formats, and look at how they influence the framing of the debate, respectively.

6.4. Research design: Case studies and methods

We chose a case study approach to look at how roles adopted by (or ascribed to) CSOs are coproduced with engagement formats and CSOs' framing activities. All three case studies involve publicly engaged CSOs and reflect different forms of engagement (invited or uninvited). At the core of our analysis are CSOs that primarily emphasize the risks and ethical problems of new technologies and are particularly critical of synthetic biology innovations (referred to in the following as "critical CSOs"). Among others, two CSOs appear frequently in our cases, namely Friends of the Earth (FoE) US and the Action Group on Erosion, Technology, and Concentration (ETC Group). Both CSOs had tracked and critically commented on the developments in genetic engineering and the biotechnology industry since the 1980s and started activities on synthetic biology in the early 2000s (Stemerding et al. 2009).

This emphasis on critical CSOs allows sounding out the boundaries of multi-stakeholder engagement, that is, how much openness in terms of deviating and critical perspectives is sought and manageable in relation to STI governance. We expect that critical CSOs challenge established framings and processes more frequently than other actors. Thus, focusing on critical CSOs shifts our perspective from interests engaged with potential applications, such as patient organizations, to broader environmentalist or sustainability agendas, and potentially indicates alternative ways of how engagement unfolds. We look at where agendas of actors possibly match, and where critical CSOs demand fundamental reshaping of debates and decision-making. The first case concerns uninvited engagement where critical CSOs took a leading role in initiating a public debate about the use of synthetic biology in a consumer product (2014). The second case is an engagement project inspired by the prior protest and aimed at fostering multi-stakeholder deliberation on synthetic biology more generally (2014–2015). The third case is an EU-FP7 research project organized under the premises of upstream deliberation under RRI's premises of upstream deliberation (2013-2017).

For our analysis, we explicitly selected engagement activities that differ in their formats and emphasize different ways of negotiating synthetic biology. Yet, since only a few critical CSOs pioneer in the debate on synthetic biology (for a first mapping of the CSO landscape on synthetic biology see Stemerding et al. 2009), the range of actively engaged critical CSOs (e.g. ETC group) or umbrella organizations (e.g. Friends of the Earth) remains limited. Moreover, our three cases not only constitute individual acts of engagement but also represent an ongoing effort to shape and reconfigure the debate on synthetic biology; they illustrate the variety of activities through which critical CSOs enrich the public discourse on synthetic biology. Initially, we were interested in societal engagement activities that favored invited engagement activities (Cases 2 and 3). The research on Case 2 called attention to one uninvited activity (Case 1) that served as main

motivation to initiate subsequent invited engagement. We chose this case to tease out (the history of) actors' positions and to broaden the notion of engagement toward bottom-up initiatives.

To reconstruct the three cases, we analyzed key documents for each engagement setting and conducted semi-structured interviews. We analyzed a range of publicly available documents, such as press releases, media articles (online), websites, dissemination material (e.g. reports or deliverables) and products of engagement projects (e.g. the Deliberation Aid), and academic articles. Moreover, we conducted 10 interviews, mostly via phone (lasting 45minutes to 1hour). Of the 10 interview partners, 6 were representatives of CSOs, 2 came from academia, 1 from industry, and 1 from research funding. All interview partners were directly involved in one or more cases, as initiators and organizers, participants, or target group (e.g. of the activities). Accordingly, the semi-structured interviews focused on the case(s) that interviewees had engaged in and addressed how CSOs initiated and participated in each case, and the issues of synthetic biology raised by critical CSOs or other stakeholders.

We recorded and transcribed the interviews and coded the transcripts, applying both inductive and deductive strategies. The aforementioned themes informed a first round of coding, indicating topics, such as the roles that actors (including CSOs) took on in each setting, how organizations became engaged, and the issues they raised. Additional codes specified and refined the analysis for each case. Such codes covered, for example, the specific frames and narratives that showed in several cases, allowing for a more detailed analysis of the material.

6.5. CSO's Engagement with Synthetic Biology

The following sections present our insights on how CSOs engaged in STI dialogues and governance, and whether and how they framed the debate on synthetic biology, both in invited and uninvited engagement activities.

6.5.1. Driving the debate: protesting "green" products

In the first case, an example of uninvited engagement, CSOs initiated a public debate about a specific consumer product. In April 2014, the company Ecover/Method (with a mission for environmentally sustainable production) announced their intention to substitute palm kernel oil with algae oil and released a test batch of detergent in the United Kingdom.[1] This provoked public protest by several CSOs, especially ETC Group and FoE US, who identified the used technique as synthetic biology or "extreme genetic engineering." Following informal communication between key representatives of the CSOs and Ecover, CSOs initiated a public debate via print and online media, and their online channels. After the New York Times had published an article on the issue,[2] ETC group criticized Ecover's decision in an open letter online.[3] Furthermore, an online petition demanded the stop for "using SB-derived ingredients" in consumer products and was signed by more than 11,500 people.[4] Besides, ETC group and Ecover intensively discussed the topic in the online blog section of the magazine *The Ecologist*.

During the controversy, actors framed synthetic biology in consumer products in different ways, along (a) the question of risk and (b) social considerations. First, CSOs highlighted concerns about safety, risks, and knowledge gaps, while Ecover claimed little environmental risks of the algae oil production. They considered it a natural process, taking place fully contained throughout the lifecycle, while feedstock of the algae (sugar

cane) could be provided sustainably (a claim challenged by CSOs). Second, despite high agreement on the substitution of palm oil, alternatives were contested in the light of sustainability. CSOs suggested coconut oil for economic reasons and issues of social justice since algae oil production would threaten the income of palm farmers of the Global South (yet, the sustainability of coconut oil remains disputed within the CSO community itself). By proposing such alternatives, critical CSOs re-introduced a strategy that industry had discarded before as unsuitable to substitute palm (kernel) oil.

Over time, the core of the debate shifted to whether the algae oil could be considered synthetic biology at all. While definitions remain contested, CSOs criticized Ecover for first claiming that the oil was "produced by synthetic biology" and then moving away from using this term (Interview B, CSO). Conceptualizing a practice as synthetic biology (or not) affects whether it is considered "revolutionary" and how it should be managed (Asveld and Stemerding 2016, 16). Thus, it influences whether the debate revolves around an individual consumer product with a determinable risk profile, or a technological approach, that is, synthetic biology, wakening overarching concerns. Critical CSOs emphasized risks of the latter, while industry eventually classified the product as resulting from established biotechnology practices. Consequently, CSOs called for transparent consumer information regarding the "ecologically friendly" advertisement of the product.

When looking at actors and roles, self-selection and mobilization of participants drove uninvited engagement, aimed at raising attention. CSOs held strong control over the debate. They presented themselves as a public social conscience and drew from an activity repertoire of former technology conflicts. Protests allowed for a high framing power of CSOs, aimed at stopping a product from entering the market and at raising awareness about issues of synthetic biology. Ecover's move away from synthetic biology raised ontological questions, but may have fulfilled strategic objectives of calming down protests. The protest allowed (and required) actors to bring in strong issue framings yet limited the scope of interaction between perspectives. Industry considered a rejection of synthetic biology as hampering dialogue but accepted additional framings or aspects as rational deliberation (i.e. aspects not represented in life cycle analysis, see also Asveld and Stemerding 2017). Thus, they welcomed critical CSOs to contribute specific contents to work toward a shared goal (i.e. sustainable solutions or substituting palm oil), but favored some positions over others:

> *"If you talk to [CSO1], they were quite well informed, they have a very specific opinion—and a very extreme one—but they tried to relate as much as possible on science and about real effects. I did like them as a discussion partner, they pushed us by asking the right questions, even if I don't agree with their point of view [. . .]. I had problems with the way [CSO2] were discussing, because they weren't using any arguments, they were just having a mantra almost. That really is a lot more difficult."* (Interview D, industry)

Eventually, the controversy was closed-down when Ecover put the use of algae oil on hold. However, the conflict prevailed and inspired invited deliberation activities where the transformation of uninvited into invited engagement proved controversial.

6.5.2. Narrowing the perspective: enabling a meta-debate

One invited engagement format inspired by the protests was the "Enabling the Conversation on Novel Biotech" project (ECNB, 2014–2015), a joint project between two

CSOs (Forum for the Future—FftF and Friends of the Earth England, Wales, and Northern Ireland—FoE EWNI), and the Biotechnology and Biological Sciences Research Council (BBSRC). Triggered by the debate around synthetic algae oil, the project aimed at enabling deliberation about synthetic biology by developing a toolkit for stakeholder deliberation, the synthetic biology Deliberation Aid (Forum for the Future, Friends of the Earth, and BBSRC 2015).

Following the controversy around algae oil in 2014, FftF set out to explore the range of perspectives on synthetic biology. Eventually, FftF, BBSRC, and FoE EWNI jointly set up a deliberation project to proceed with the debate (Interview E, initiator). The three organizations had been interested in synthetic biology before to varying degrees: FftF, a charity and non-profit organization with the aim to accelerate sustainable change had already conducted multiple projects on synthetic biology, mostly supporting organizations in considering sustainable practices. FoE EWNI, an NGO, had done little work about synthetic biology, albeit FoE international having been active around biotech and genetic engineering. BBSRC, a UK research funder for biotechnology and biological science, had funded synthetic biology and respective dialogue activities since the mid-2000s.

The ECNB project conducted expert and stakeholder interviews for a first draft of a toolkit for deliberation (the Deliberation Aid) and collected feedback from key actors, including CSOs (such as ETC Group), synthetic biology scientists, and industry representatives in an online consultation. Then, the updated version was discussed in a roundtable workshop with about 30 stakeholders, including scientists (social sciences, ethicists, and biological sciences), companies (including Ecover), users of specific products, and CSOs (yet without participation of ETC Group and Friends of the Earth US).
Developing a tool for guiding deliberations on the "sustainability of a potential applications of synthetic biology" (Forum for the Future, Friends of the Earth, and BBSRC 2015, 5) shifted the debate from the vivid controversy on algae oil in consumer products to including a range of perspectives on synthetic biology in different application contexts. Editors of the Deliberation Aid collected various (partly contradictory) definitions of synthetic biology, sketched an infographic for appraising synthetic biology applications, and drafted application examples and hypothetical personas representing different perspectives. In the workshop, stakeholders were asked to reflect on framings and perspectives on synthetic biology, to discuss "whether [the questions of the Deliberation Aid] were the right kind of questions" (Interview J, initiator) and to adjust the presented examples. This shifted the deliberation from individual positions of stakeholders to a meta-debate on how to best discuss synthetic biology. While individual conflicts remained unaddressed, the controversy on algae oil lingered in the background:

> *"[S]o this whole debate around Ecover was [. . .] a bit of an elephant in the room, [. . .] but we didn't look at it specifically, although [. . .] people would have mentioned that, and one of the companies involved, the main company that produced it [the algae oil], [. . .] Solazyme, [. . .] and Ecover were into it [. . .] . . ."* (Interview J, CSO)

Accordingly, critical CSOs fundamentally criticized the process framing:

> *"The question they were asking us was: in what way can we use synthetic biology that you will be comfortable with or it would be okay to use these biotech techniques that you would be comfortable with. That wasn't the discussion we wanted to have."* (Interview B, CSO)

Besides, CSOs claimed not to have been invited face-to-face and interpreted the restrictive invitation policy as a strategy to mainstream framings. Thus, rendering the debate more abstract limited the framing and participation opportunities for critical CSOs, despite the format's open-ended conversation. Eventually, the Deliberation Aid was published online as the main result of the ECNB project and has been listed as a best practice example for multi-stakeholder engagement on emerging technologies by other projects (e.g. by the H2020 project PRISMA).

Regarding opening up, formats, actor roles, and framing changed considerably compared to the public protest. Aimed at enabling an open debate, the case moved toward an invited multi-stakeholder engagement to contribute to sustainable innovation through synthetic biology. Shifting control over framing and invitation policy from critical CSOs to project organizers simultaneously enriched and limited the range of participants. The range of involved stakeholders was broadened (including social sciences, ethicists, biological sciences, companies, users of specific products, and some CSOs), yet, engaging critical CSOs proved challenging. Moreover, critical CSOs considered their framing power limited and suspected the project to presume the innovativeness of synthetic biology, restricting a fundamental rethinking of synthetic biology's sustainability. Thus, we conclude that lingering expectations about the format's objectives resulted in a situation where the abstraction of the issue neither eased the situation for industry nor met expectations of critical CSOs.

6.5.3. Variety and indifference: Framing in upstream engagement

The third case is a large-scale project fostering societal dialogue under RRI: SYNENERGENE (funded under FP7 of the European Commission) consisted of 27 consortium partners, coordinated by the Karlsruhe Institute of Technology (KIT). Between 2013 and 2017, it conducted different activities, including collaborations with iGEM and artists, several open forums for stakeholder dialogue, and a variety of public and stakeholder engagement events across Europe. SYNENERGENE involved stakeholders from science, industry, civil society, education, arts, and the broader public in different capacities (as consortium partners, organizers of events, speakers at events, facilitators, target groups, etc.). Two CSOs (ETC Group and What's Next Forum) were project partners due to previous collaborations, and both were critical toward synthetic biology or expressed a need for a broad public debate.

For stakeholder engagement, SYNENERGENE organized five Open Forums (policy, media, industry, science, and civil society). What's Next Forum chaired the Civil Society Forum whose most prominent activity was the web-based platform SynBioWatch. It broadcasted "civil society views" (Interview B, CSO) and served as a "gatekeeper" to the wider CSO community. Here, CSOs had strong agenda setting and framing power regarding contents and formats. Consequently, SynBioWatch reflected CSOs' attitude toward synthetic biology, promoting a comprehensive rethinking of and regulatory oversight of synthetic biology in the light of sustainability—from tips for consumers (e.g. "shopping guides" for non-synthetic biology products) to technical and regulatory backgrounds. SynBioWatch also featured two webinars and broadcasted the Captain Hook Awards for Biopiracy (all in 2016). Alongside, the Civil Society Forum held several meetings to discuss RRI with the CSO community (Coenen 2017) and organized dialogues between civil society and policymakers on synthetic biology governance, for example, at the World Social Forum/World Forum on Science and Democracy, the International Labor

Association, and the Thirteenth Conference of the Parties (COP13) to the Convention on Biological Diversity (CBD). CSOs acknowledged the role of the latter in initiating and stimulating an open debate:

> *"[O]ne of the reasons we did it there is [that] it [synthetic biology] is a very active topic at the CBD. [A]nd having that space to meet together and talk through the different issues really does form the ability to handle the negotiations [. . .] [-] whether that's for indigenous groups who we were hearing about the issue from for the first time or for national governments who are still trying to get up to speed on the issue, and to have done that together rather than in the negotiating setting where everything is more political and polarized. So, this was good."* (Interview B, CSO)

Yet, while the Civil Society Forum was highly active, interactions with other Open Forums remained sparse.

In general, SYNENERGENE aimed at fostering public and stakeholder dialogue by convening over 120 engagement events, including stakeholder workshops, science cafés, film festivals, arts exhibitions, theater productions, and an online debate (Coenen 2017). Many events were organized by engagement experts or scientists and had an informing or educating character (Bauer and Bogner 2020). Consequently, a framing of synthetic biology as societal progress and a retraction to meta-frames like RRI often dominated. Yet, one main event of the project, the Amsterdam Forum, was an outstanding example regarding its involvement of stakeholders with contrasting views on synthetic biology, including CSOs, scientists, and industry representatives. In this event, CSO representatives challenged the promise of "synthetic biology's problem-solving capacities" and re-defined the societal progress frame by pointing toward causes of challenges and alternative solutions to synthetic biology (Bauer and Bogner 2020). Here, the potential of CSOs to open up the debate became visible.

Overall, different actors in SYNENERGENE appreciated setting their own agendas and designing engagement processes according to their needs. Yet, CSOs seemed most successful in broadcasting their perspectives in a way that usually exceeds their capacities:

> *"It's certainly been a very useful vehicle for enabling discussions within civil society and it's funded and allowed a bunch of discussions that may not otherwise have been possible around synthetic biology. And that, in itself, has created a deeper and more subtle analysis, so that's good."* (Interview B, CSO)

Therefore, CSOs acknowledged the project's contribution to societal debates about synthetic biology, irrespective of concrete outcomes.

In terms of opening up, SYNENERGENE emphasized innovative forms of engagement. The activities and events constituted the main output and were accompanied by a range of academic and practitioner reflections. The website SynBioWatch remained active after the project but fizzled out over time. SYNENERGENE's open and flexible format allowed critical CSOs to appear in different roles, from organizing dialogues, workshops, and conference sessions (as project partners) to broadcasting critical aspects of synthetic biology (as collaborators of SynBioWatch). These formats seemed to serve critical CSOs well, fitting a general agenda of activism and public mobilization. While exchange between perspectives only occurred selectively, flexibility allowed to easily link

them to general debates on synthetic biology; eventually, the various opportunities to engage resulted in a broad range of framings sustained in parallel. Thus, projects such as SYNENERGENE provide a reservoir of argumentation for public debates due to their openness in framing and formats, while remaining rather far from decision-making contexts (with the exception of individual events).

6.6. Opening up roles, frames, and formats: dynamics of CSO engagement

Now, how does the engagement of critical CSOs open up or close down debates on synthetic biology, in particular under RRI? We showed how roles of critical CSOs, engagement formats, and framings are interrelated. Originally, critical CSOs raised awareness against specific products and exerted pressure on industry through protests. Subsequent invited engagement formats shifted the scope from contesting products to multi-stakeholder dialogue, indicating whether and under which conditions synthetic biology may be acceptable, and which questions to address beforehand. Thus, the issue at stake was opened up and moved upstream, but turned more abstract at the same time. Aimed at fostering societal dialogue, a third format rendered synthetic biology even more fragmented and abstract, but allowed the broadcast of different perspectives simultaneously.

We found that each engagement format allowed for different roles for critical CSOs. Regarding (industrial) decision-making, critical CSOs insisted on being included: their ideal of self-empowerment drove public protest when CSOs acted on behalf of a public conscience and used protests to exert pressure on industry. Critical CSOs kept these positions in invited engagement formats, while other CSOs organized and facilitated multi-stakeholder dialogues. These organizers determined framing and participation policy, resulting in a simultaneously enriched and limited landscape of participants: despite involving a broader range of actors, critical CSOs largely remained outside critics. SYNENERGENE, again, offered different roles for critical CSOs as project partners (organizing dialogues etc.) or collaborators (providing information on SynBioWatch). Thus, distant from decision-making, critical CSOs engaged without having to alter their own or others' perspectives.

Consequently, we argue that participation of critical CSOs is largely defined by their (perceived or realized) framing power. Uninvited formats were dominated by framings of critical CSOs, for example, defining synthetic biology as "extreme genetic engineering"[5] which re-occurred in all three cases. This framing puts synthetic biology in a specific historical-discursive context—genetic engineering—a contested practice, which synthetic biology takes to the extreme. In contrast, other actors framed synthetic biology as innovation with high economic, societal, and sustainability potential for many areas (Bauer and Bogner 2020). Also, rather than different framings of synthetic biology, whether to conceive a particular practice as synthetic biology turned out crucial, as this affects how the respective practice is assessed and managed. In any case, conflicting framings offered little scope for (balanced) negotiation and reconciliation of perspectives.

In invited formats, industry and organizers found that fundamental oppositions to synthetic biology hampered dialogue, but considered bringing up hitherto marginalized aspects (e.g. for assessment) acceptable. Critical CSOs, again, saw invited engagement formats as pre-framed and industry-friendly when conflicting with the objective to dismiss

synthetic biology altogether. Yet, some invited engagement formats allowed CSOs to perpetuate their framing of synthetic biology, yet risked to render the debate abstract by shifting the focus from specific applications to benefits, risks, or ethical concerns of synthetic biology in general. Overall, we argue that the interplay of format, roles, and framing fundamentally affects the maneuvering space for CSOs and their potential to engage in, alter, or open up debates on synthetic biology.

Yet, the outlined cases not only represent individual engagement activities, but parts of a continuous and dynamic public debate on synthetic biology, as references to prior technology conflicts indicate. Accordingly, policy anticipated and evoked (invited) public debates on synthetic biology (like nanotechnology before) in a precautious manner—just to realize that large parts of the public would not engage as expected. This shows that public debates do not exist "out there" but are indeed constructed by actors in different ways.

We find that CSOs' engagement largely depends on the expectations of their supporters (e.g. whether products meet requirements for being "ecologically friendly") and existing public awareness about the issue at stake. While industry depends on consumers for public reputation, CSOs need to justify their engagement because they rely on public donations. Consequently, only few CSOs engage in non-climactic issues (such as synthetic biology) and, if they do, usually ensure that they are connected to other issues on their agendas (e.g. sustainability or biodiversity). As their supporters guide CSOs' decisions (how) to engage in these debates, opposing consumer products and individual producers has proven to be a promising strategy for critical CSOs to reach their goals in an effective and persuasive way (Hess 2010, Schurman 2004, Weber, Rao, and Thomas 2009).

Accordingly, proximity to decision-making turned out to be crucial: critical CSOs considered engagement successful when they contributed very specifically (e.g. reaching a moratorium on synthetic biology products entering the market). In terms of "opening up," this implied that framings (of industry and critical CSOs alike) remained rather closed. This incommensurability of perspectives profoundly challenges RRI's ideal of a "balanced" dialogue. Yet, critical CSOs also appreciated abstract engagement activities accommodating their perspectives. While they considered mobilizing a broad public dialogue core, low public interest in synthetic biology limited their possibilities to engage. When funded, however, upstream engagement offered a much-welcomed opportunity to broadcast perspectives and engage in dialogue. In terms of opening up, this enriched the overall public debate by providing a reservoir of argumentation, even if interaction between framings (and RRI's hoped for "balancing of views") remained restricted.

Besides, we argue that engagement located at a "middle range" of proximity to decision-making proved difficult as it evoked strategic ambiguities: limited clarity about the overall objective led critical CSOs to perceive some activities as delegating conflict, although such presumptions were never claimed explicitly. Critical CSOs perceived the format as narrow and closed down, aligning with a general innovation perspective. Accordingly, they shied away from contributing their framings and meta-perspectives in direct interaction, while definitions and appraisal questions used to stir deliberation mirrored (some) of their arguments. This ensured "opening up" of the setting to a certain extent but did not change its overall framing.

6.7. Conclusions

So, overall, what are the implications for STI governance, and in particular RRI? To determine factors that contribute to opening up, we looked at different engagement formats and showed that CSOs' participation depends on their agenda and power to frame the scope of the debate. Critical CSOs acknowledged all engagement formats as long as purposes were clear and underlying expectations kept at bay.

With regard to RRI, critical CSOs suspected its underlying innovation agenda would make raising critical arguments difficult. This illustrates concerns about RRI "mainstreaming" debates by not considering the whole range of positions equally (Bauer, Bogner, and Fuchs 2021). To counter this, they reframed the issue of synthetic biology and linked it to broader perspectives (e.g. biodiversity, or a specific conception of sustainability) to unify critical voices and to mobilize their clientele. Accordingly, we find that RRI's aspired "balancing of perspectives" turns out a balancing act itself as it assumes a mutual understanding about the basic question at stake. This can (partly) be reached by expanding and reflecting one's perspectives, but remains difficult to achieve as consensus on the world of facts (if possible at all) does not necessarily entail consensus about the perceived legitimacy of synthetic biology, and incommensurable positions are hardly to be "balanced." Accordingly, various engagement formats at least ensure that many positions are addressed, although separately. In other words, prioritizing one way of engaging (i.e. invited engagement with a strong framing power of organizers) risks restricting the scope of a public debate from the outset.

In our cases, we showed that each engagement format had a different objective and related to opening up and closing down in different ways. While protests virulently opened up the debate by laying out strong perspectives and hitherto marginalized issues, invited engagement aimed at placing them within a wider landscape of perspectives. Hence, systemically speaking, a multitude of engagement formats ensures a distributed public debate on synthetic biology, exceeding the value of individual exercises. This is particularly important as debates on emerging technosciences are dynamic, and the relation between upstream and downstream engagement is complex. While not empirically researched in this article, studies on public participation in other contexts (i.e. genomic research and genetic testing) suggest that upstream and downstream engagement relate differently to affectedness and hence, problematize different aspects of the issues at stake (Felt and Fochler 2010). Thus, they enrich the public debate on technosciences rather than substituting one another. Accordingly, STI governance needs to provide spaces and recognition for different ways of engaging with (organized or unorganized) publics. This would also relieve individual processes from the pressure to meet all requirements of RRI at once.

Finally, calling for opening up STI governance aims at better representing certain social groups and standpoints. However, opening up does not only relate to the quantity of engaged actors but to the possibility of critiquing ingrained concepts and styles of thinking that represent a wide variety of social groups and standpoints. Therefore, it is not enough to simply increase opportunities of societal engagement within the framework of RRI; rather, basic mindsets and assumptions—including the concept of innovation itself—need further questioning. Our findings on actor roles, engagement formats, and framing provide a starting point for further reflection.

6.8. Footnotes

1. https://www.theguardian.com/environment/2014/apr/02/ecover-algae-laundry-liquid-palm-oil (accessed 24 May 2022).
2. https://www.nytimes.com/2014/05/31/business/biofuel-tools-applied-to-household-soaps.html?_r=0 (24.5.2022).
3. http://www.etcgroup.org/content/open-letter-ecover-method (accessed 24 May 2022).
4. https://www.syntheticisnotnatural.com/ (accessed 24 May 2022).
5. https://www.etcgroup.org/issues/synthetic-biology (accessed 15 January 2023).

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7. Case Study 3: Opening up computational modelling in the context of nano risk governance

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7.1. Abstract

Computational modelling has increasingly been used for policy-making and regulation in a broad range of fields – from climate change to nano risk governance. This chapter explores the ways in which a particular computational tool may (or may not) contribute to opening up risk governance by looking at how it convenes stakeholders, the conceptual shifts it is based on, and the uses it affords. We find that within the context of risk governance, opening up in and through computational modelling is mobilized in a very specific and embedded way. Therefore, efforts to engage stakeholders and broaden out the scope of the tool remain limited and ambiguous. However, a consistent reflection on the tool development indicates that concepts of responsibility such as responsible (research and) innovation (R(R)I) have well found their way into the field of nano risk governance.

7.2. Governing nanotechnologies through modelling

Nanotechnologies have served as a prime example of how to govern emerging technologies for more than 20 years. They raised expectations of great economic and societal benefits as well as fears of potentially adverse effects. Thus, they are a case example of an emerging technology prone to public contestation (Rodríguez 2018). Emerging technologies are characterized by complexity, uncertainty, and ambiguity (e.g., Klinke and Renn 2021, Demortain 2017, Åm 2015). Science, technology, and innovation governance ('STI governance') considered nanotechnologies a pilot study field for how to handle emerging risks (e.g., Miller and Wickson 2015, Åm 2015). Over time, governance has focused more and more on nano*materials* as an attempt to normalize developments within existing governance frameworks.

Even after more than 20 years of discussion, nanomaterials still pose a challenge to scientific fields like regulatory testing, which are supposed to support decision-making. This is due to remaining knowledge gaps like effect mechanisms on humans and the environment, as well as the sheer abundance of nanomaterials and deriving high costs of systematic testing. In combination with wider ethical-political demands, like minimizing animal suffering by reducing animal testing[21], these challenges have pushed research and regulation to increasingly explore approaches of computational modelling (Haase et al. 2018, Worth et al. 2017). In toxicology, computational ('*in silico*') methods complement traditional approaches to determine (adverse) effects of substances, like methods using living organisms ('*in vivo*') or cells ('*in vitro*') (Hemmerich and Ecker 2020). Moreover, computational modelling is applied to risk analysis and management (Erbis et al. 2016), including synthesis and release of nanomaterials; environmental and human exposure or

[21] https://ec.europa.eu/environment/chemicals/lab_animals/3r/alternative_en.htm (accessed 04 September 2021) Directive 2010/63/EU of the European Parliament and of the Council of 22 September 2010 on the protection of animals used for scientific purposes Text with EEA relevance.

fate; and supporting decision-making in policy and industry (see Trump et al. 2018 with focus on multi-criteria decision analysis, Erbis et al. 2016, with regard to risk analysis, Subramanian, Semenzin, Hristozov, et al. 2016, Lamon et al. 2019). Consequently, modelling gained substantial interest among stakeholders from science, policy and other fields (Erbis et al. 2016, Subramanian, Semenzin, Hristozov, et al. 2016, Trump et al. 2018, Haase et al. 2018).

The diversity of analyses to assess and manage risks corresponds to a variety of modelling approaches: they range from "-omics approaches" (such as genomics, proteomics, metabolomics) (Interview 07) to Quantitative Structure-Activity-Relationships (QSARs) and Physiologically Based (Pharmaco) Kinetic modelling (PB(P)K) (Worth et al. 2017) to multi-criteria decision analysis (Trump et al. 2018) or Bayesian networks (Erbis et al. 2016, for a case study see Marvin et al. 2017) among others. To do justice to this variety of approaches for determining risk assessment and management, comprehensive modelling tools promise to evaluate risks in an integrated way. In this chapter, we present one illustrative example of such an integrated tool.

The European Commission funded several projects to develop integrated modelling tools for determining and governing risks under the research framework programs FP7 and H2020. These tools are supposed to ensure scientific adequacy and correspond to feasibility requirements by potential users, like industrial producers, regulators, policy makers and other actors at the same time (Interview 08). Moreover, these tools are expected to provide an effective and efficient way for governance practice by integrating risk, impact and decision analysis, especially in the light of sustainability (Malsch, Subramanian, Semenzin, Hristozov, and Marcomini 2015, Linkov et al. 2014).

Generally speaking, computational models need to be tailored to specific application contexts to be meaningful (e.g. see Saltelli et al. 2020, for the context of infectious disease modelling). This tailoring translates the scientific and public discourse into a technical, or rather virtual, object, which constitutes a manifestation of these discourses. Thus, each model constructs the relations between the modelled objects anew: it foregrounds and backgrounds aspects of complex matters in order to become meaningful and useful (Sismondo 1999, 252). How this is done varies between modelling approaches. In any case, models are never only "representations of reality", even if they strive to do so, but always exert agency (Sismondo 1999, 252). Therefore, we consider models an outstanding case to study which understandings of matters are foregrounded (or not), how risk governance is framed, and how models eventually open up or close down the discourse at hand (Stirling 2008).

This chapter looks at one integrated modelling tool to investigate the agency of computational modelling in the context of governing nanomaterials. We are interested in opening up or closing down with regard to determining and handling risks in particular, and how they are encouraged or discouraged by the tool. We consider the collaborations of actors and the concepts that the tool is based on as an approximation of how risk governance is understood. Moreover, we draw from the concept of affordances to see how integrated modelling tools encourage some uses while limiting others, and how this relates to engaging stakeholder and expert communities. In short, we look at how integrated modelling tools stabilize or destabilize understandings of risk governance. To answer this question, we first introduce perspectives on the agency of models, and how affordances relate to opening up and closing down (section 2 [section 7.3 of the thesis]). In section 3

[section 7.4 of the thesis], we present our research approach and methods. This includes an in-depth case study of a modelling tool, the SUN Decision Support System ('SUNDS tool'), where we analyze who was involved in its development, which conceptual aspects were considered, and how it is embedded *in socio* (section 4 [section 7.5 of the thesis]). We then discuss the agency of modelling in risk governance (section 5 [section 7.6 of the thesis]) and present concluding remarks (section 6 [section 7.7of the thesis]).

7.3. 'Opening up' the agency of computational modelling

Recently, computational modelling has become an interesting research object for science and technology studies (STS) and related fields like technology assessment (TA) or philosophy of sciences. Scholars have investigated its meaning for science, in particular in relation to other instruments of cognition (Sismondo 1999). In the policy context, they have focused on the process of translation to and interpretation by policy. This is particularly important due to a general trend towards objectivity in public life which implies that decisions are increasingly accompanied by scientific validation (Sismondo 1999, 247). Thus, increasingly, models have become "ubiquitous in public policy and corporate strategy, as well as applied and pure science" (Sismondo 1999, 247). Accordingly, scholars have investigated computational models and their role in decision-making in policy or corporate strategy. They have been discussed in the context of complex policy matters like climate change (e.g., Edwards 2011, Müller 2010), energy systems (e.g., Taylor et al. 2014), infectious disease modelling, including the recent COVID-19 pandemic (e.g., Saltelli et al. 2020, Manzo 2020, Christley et al. 2013, Stirling and Scoones 2009), economy policy, economy and financial markets (e.g., den Butter and Morgan 1998, MacKenzie and Spears 2014), the labor market and unemployment (e.g. Allhutter et al. 2020), STI policymaking in general (e.g., Ahrweiler 2017), or material regulation (including modelling's effect on it, see e.g., Thoreau 2016), to name just a few. On a practical level, scholars have reflected on how to better align model development with requirements of policy and science (e.g., Saltelli et al. 2020, van Voorn et al. 2016, among many others).

Despite their manifold fundamental differences, these perspectives agree that computational modelling is neither a neutral instrument nor produces objective or self-explanatory results. Rather, they emphasize modelling's agency and point to its specificity in scientific and political contexts: computer models always serve a specific purpose (Saltelli et al. 2020). They need specific input to be processed in a certain way to produce the required output – a process that, in principle, holds true for scientific models more generally, computational, conceptual, or physical. Yet, in comparison, computational models go further: they strive to become "analogues of physical systems" and "should *behave* the same way as the things they represent behave", including that their outputs should be comparable to real-world data (Sismondo 1999, 249, emphasis original). However, STS scholars have pointed out that models exceed these aspirations of becoming analogies of physical systems, possessing their own agency. As Christley et al. (2013) put it: a model is never an "*in silico* representation of a system, free from human influence, but rather is socially produced within the discourses of its representation" (Christley et al. 2013, 2, emphasis original). In principle, this holds true for all forms of knowledge; accordingly, all kinds of knowledge exert agency. However, the agency of theoretical and experimental knowledge appears largely hidden. In contrast, the complexity of computational approaches like simulations, highlights agency as it shows the extent to

which models rely on simplifying assumptions (Sismondo 1999, 252-254). Thus, this renders the social construction of models visible and emphasizes the interpretative flexibility of modelling factors (like uncertainty, see Christley et al. 2013).

The design of computational models is a complex process which relies on specificity and expertise: it requires domain-specific expertise for selecting variables, measurements, and models. At the same time, their capability to reflect heterogeneous epistemological and ontological aspects is the very strength of models (Mansnerus 2013, 268). Models span between the ideal and the material, as well as between different scientific approaches, disciplines, and societal realms like science and policy. They provide a focus for sharing expertise between actors and serve as knowledge devices (den Butter and Morgan 1998, 471). Accordingly, for example in the field of risk governance, computational modelling constitutes an area to (re-)negotiate purposes, requirements, values and norms in risk governance. This is all the more important as regulatory science (i.e., sciences supporting risk governance) is already "the product of a mutual construction of scientific paradigms and policy frameworks" (Demortain 2017, 147).

This chapter looks at how one specific modelling tool affords different aspects of risk governance in the light of opening up and closing down. In STI governance, or more precisely in the social appraisal of technologies, the process of framing perpetuates existing power structures by prioritizing some arguments while marginalizing others. To strengthen transparent and legitimate decision-making, closed down framings need to be opened up. Opening up considers a broad range of perspectives in STI governance consistently by presenting a range of policy options in a multi-faceted way instead of definite suggestions (Stirling 2008). For Stirling, opening up and closing down constitute subsequent and invariable steps of decision-making, but recently, scholars have transferred his concept to the context of responsible innovation (see also Chapter 3 of this thesis). Here, opening up and closing down are conceptualized as balanced, simultaneous, and temporal states (van Mierlo, Beers, and Hoes 2020). This shows that understandings of opening up and closing down are adaptable and manifest differently according to the respective context.

Looking at computational modelling for policy, opening up and closing down solidify in specific technological constellations. These constellations affect the purpose and framing of models, as well as individual steps of modelling. Thus, opening up and closing down shape how the agency of models unfolds. Most of the literature on agency and the roles of models in governance above promotes a strong social-constructivist perspective. In contrast, we set out to also pay tribute to the material, i.e., virtual conditions that shape agency of modelling. Consequently, we consider both the human and the virtual in our investigation of opening up or closing down in relation to integrated modelling tools. In a first step, our research interest remains at the discursive level, where framing foregrounds specific aspects of the issue at stake. As such, a narrow framing tends to close down the debate, marginalizing alternative perspectives or assessments with the tendency to exclude specific actor groups (cf. Sulmowski 2017). We take this as a starting point to investigate how actor constellations form in risk governance modelling, and to explore the conceptual basis of the modelling tool.

In addition, we mobilize the concept of *affordances* (e.g., Bloomfield, Latham, and Vurdubakis 2010, Hutchby 2001, Jarzabkowski and Pinch 2014). Thus, we introduce a sociomaterial perspective to analyze opening up with regard to computational models for

nano risk governance. Generally speaking, technology affordances describe how artefacts enable and constrain human behavior (ten Oever 2021, 345, citing Hutchby 2001, 441). They are anchored between realism and social constructivism as they consider the material as something that exists and has real-life effects. By so doing, they emphasize the co-constitution of the sociomaterial, i.e., that humans and material bring each other into existence in a certain way (Hutchby 2001, Allen and Marshall 2019). Affordances therefore allow to understand "the action possibilities that our interactions with matter affords us" (Allen and Marshall 2019, 105). Specifically, affordances highlight that humans and matter are tightly interwoven. They are "bound with specific, historically variable, ways of life" (Bloomfield, Latham, and Vurdubakis 2010, 428, cited by Allen and Marshall 2019, 105-106). Moreover, they are strongly relational as "[a]ny object can afford various action possibilities in the social context of its use" (Allen and Marshall 2019, 105-6). The concept of affordances can easily be extended from the physical to the virtual world. Like physical technological objects, basic virtual structures like code or architecture are socially constructed and affect human behavior. And like physical technological objects, affordances have political agency and produce "consequences logically and temporally *prior* to any of its professed uses" (Winner 1980, 125). Simply put, they embody certain values that render them prone to embedding politics (Lin 2021, 2).

Besides affordances, STS offers various approaches of how to conceptualize user-technology-interactions. One of the most prominent concepts is the concept of scripts, which defines a particular course of action (Akrich 1992), though it has been criticized for overemphasizing the role of the designer, similar to Woolgar's 'configuring of the user' (Woolgar 1990). Consequently, scripts tend to underestimate the encounters between materials and humans (Schulz-Schaeffer 2021, 80, referencing Hyysalo 2010). Although they are, in principle, not limited to signs, scripts largely consider "technology as text" (cf. Fallan 2008, 63, Akrich and Latour 1992, 259). However, for our case study, this unidirectionality of the user-technology-interaction deems unsuitable. In contrast, affordances allow to sketch out perspectives expressed through computational modelling tools. At the same time, they avoid overemphasizing intentionality in tool development and do not suggest full control over the tool's use.

Nonetheless, to adequately address our case study, we need to carefully reconsider some aspects of the concept. First, Schulz-Schaeffer (2021) emphasized that affordances focus on common properties of the user. Thus, technologies analyzed through affordances are usually accessible to a broad range of people. For our case study, this notion of *common accessibility* needs to be considered carefully, as it is set in a highly specialized context, although the modelling tool itself is publicly accessible upon registration. Second, the concept of affordances only considers social relations to a limited extent and often remains bound to the technical components of a sociotechnical system (Lin 2021). Thus, as noted above, we look at *social aspects* more explicitly. In particular, we analyze the interdisciplinary collaborations as well as the conceptual bases of the tool in the light of opening up and closing down.

Overall, we are interested in how one specific integrated modelling tool stabilizes or destabilizes aspects of nano risk governance in the light of opening up and closing down. To answer this question, we investigate how actor constellations form in modelling, explore the conceptual basis of the tool, and look at how it affords different uses. To do so, we address three questions:

- *How are stakeholder views and expertise included (or excluded), organized and manifested by the SUNDS tool?*
  Here, we consider the actors involved and their roles during tool development. Which actor groups have been engaged and in what way? Moreover, we are interested in the constellation of scientific disciplines that enabled the development of the tool. Which disciplines were predominantly concerned with the development and how were disciplines engaged whose expertise does not cover the main mandate of the tool?
- *Which aspects of risks does the SUNDS tool reproduce and manifest?* Here, we look at different conceptual shifts featured in the tool. Which understandings and assumptions of determining and handling risks can be detected from the tool's outline? What are implications regarding broader understandings of risk analysis and management?
- *Which imagined contexts of use are emphasized by the SUNDS tool?* To explore this question, we investigate the application contexts that the tool is imagined in, dependent on different actor perspectives. How are integrated models considered to afford concrete procedures of risk assessment? What is their role in basic research? And how do these different understandings affect the tool's regulatory embedding?

7.4. Case and methods

For our analysis, we chose an illustrative case of a computational tool developed by the Sustainable Nanomaterials project (SUN) under the 7th framework program of the European Commission. The call for proposals under which the project was funded focused on safety in nanoscale production and products, including aspects like life cycle perspectives and methods to enable prediction (European Commission 2013, 22). The SUN project developed the SUNDS tool, which consists of a semi-quantitative screening tool for benefits and risks (tier 1) and elaborate quantitative risk and socioeconomic assessments (tier 2) (Subramanian, Semenzin, Hristozov, et al. 2016, Malsch et al. 2018).

To select this case study, we screened various EU-FP7 projects that aimed at developing integrated tools for computer-assisted risk governance and excluded projects that only supported parts of it, like the automatization of testing procedures. A first run of interviews with key actors only referred to a few tools (e.g., SUN, GUIDEnano, SimpleBox4Nano). We also considered practicalities for the selection, like the comprehensiveness of analyses integrated in the tool, or easy access to the tool and its descriptions; moreover, we looked for tools whose development was (at least preliminary) finalized at that time of investigation.

We considered the SUN project an interesting case to investigate how the affordances of the final tool came about. The SUNDS was developed at the intersection between science, industry and policy to provide comprehensive guidance for decision-making. Thus, we expected to gather insights on their relations in terms of values and conceptions reproduced by the tool, and on the practices it affords. Moreover, while the original project ended in 2017, follow-up projects develop the tool further. This allows us to identify general tendencies of computational modelling tools for nano risk governance. Lastly, the project conducted extensive stakeholder elicitation in form of a mental models analysis (Malsch et al. 2017, Malsch, Subramanian, Semenzin, Hristozov, and Marcomini

2015). This provided us with the opportunity to investigate negotiations about core aspects of modelling, in addition to the actual tool. Also, due to the multitude of partners, the project provided a broad range of information material, which reflect on specific tasks like the design of individual analyses or parts of the tool, the use of multi-criteria decision-making analysis, and further opportunities to contextualize, apply or extend tool. Due to these efforts, the SUN project and the SUNDS allow for different insights on how to govern nanomaterials.

Methodologically, our analysis is based on a qualitative content analysis of documents about the SUNDS, such as deliverables, peer-reviewed papers, fact sheets, conference proceedings, and workshop protocols. Additionally, we conducted semi-structured interviews: first with key actors to gain an overview of the scientific state-of-the-art of modelling and the research field in general (7 interviews lasting approx. 45 min); second, with scientists, industry stakeholders, modellers, and policy makers who were involved in developing or applying the tool (9 interviews lasting between 45 min and 2 hours). The interviews were conducted via phone or Skype and recorded. The second type of interview was transcribed and coded by MaxQDA, using a combination of deductive and inductive codes. Findings from the document analysis and interviews were contextualized in debates on governing emerging technologies and risk, as well as STS literature on modelling, affordances or risk governance. Moreover, as the tool is publicly available (in its updated version[22]) and offers 'case studies' (i.e., given examples of materials), we also explored the tool ourselves. Given our limited expertise, this can only provide a rough overview on the tool's functions rather than an in-depths analysis. Thus, for analyzing affordances, we also rely on descriptions of developers and users. We followed indications of how actors perceived the intended use of the tool, their own role as well as the roles of other actors in tool development. To see where actors' perceptions of the tool did not align, we looked at how they stated conflicts or mismatches in understandings and evaluations of the tool (e.g., regarding risk, sustainability, innovation, and the evaluation of the tool). Particularly, we were interested in the novelties and strengths of the tool. Thus, we screened for described novelties in comparison to established approaches and challenges that had to be resolved during tool development.

7.4.1. SUN and the SUNDS

The SUN project (2013-2017) set out to develop risk assessment and management strategies along the life cycle of nano-enabled products and to integrate findings and methods into a computational modelling tool. It was coordinated by the University of Venice and had an overall budget of approx. € 13.585.000.[23] The consortium consisted of more than 35 partners, including universities, other public and private research institutions, consultancies, organizations for technology transfer and firms. For greater impact and information, "[k]ey players from ECHA, OECD, U.S. EPA and Health Canada" participated in the SUN advisory board.[24]

The structure of the SUN project showed three different themes: products and materials, risk assessment and safer product and process design.[25] To determine risks and

[22] https://sunds.gd/ (accessed 28 September 2021).
[23] https://cordis.europa.eu/project/id/604305 (accessed 18 September 2020).
[24] https://cordis.europa.eu/project/id/604305/reporting/de (accessed 21 July 2022).
[25] http://www.sun-fp7.eu/project-2/sun-structure (accessed 27 October 2020).

management strategies, SUN conducted a broad variety of analyses on the characterization of materials along the lifecycle, human and environmental hazards, environmental exposure, environmental fate, and exposure of target groups in specific scenarios, like consumers or workers. To demonstrate the relevance of the analyses, the project selected seven case studies of real-life nano-enabled products (Marcomini and Hristozov 2017). Exploring both experimental settings and computational modelling approaches, industrial partners evaluated "the new methods and tools developed in the project against real nanotechnology applications" (Marcomini and Hristozov 2017, 2). Overall, the project generated a broad variety of outcomes, including environmental health and safety data on nanomaterials, novel or adjusted experimental testing methods and protocols, intelligent testing strategies for nanomaterials, advanced modelling approaches, and, eventually, the SUNDS (Marcomini and Hristozov 2017). Stakeholders like regulators, industrial stakeholders, and insurers "were engaged in a series of interviews and workshops to discuss its [the tool's, author's note] design and functionality" (Marcomini and Hristozov 2017, 23, see Malsch, Subramanian, Semenzin, Hristozov, and Marcomini 2015, Malsch et al. 2017, for a detailed analysis). To finalize the tool, one partner (University of Venice) integrated input from other content-specific work packages (Interview 03, Interview 04). The tool, its methods and even codes of some models are publicly available, and the final tool has been updated and adjusted[26] in subsequent EU-projects, e.g., CaLIBRAte[27] and BioRIMA[28].

The SUNDS is a webtool for sustainable manufacturing, comprising risk assessment and risk management strategies for key stakeholders. It allows a product-oriented assessment of benefits and risks to contribute to sustainable manufacturing (Malsch, Subramanian, Semenzin, Hristozov, and Marcomini 2015). It is intended to be used by organizations to support sustainability assessment and risk management (Malsch et al. 2017, 466). The SUNDS is freely accessible upon registration. The user needs to create a case study and then select between the different tiers, i.e., between screening or assessing risks. The latter requires creating a scenario and allows to select between modules for 'risk assessment', 'risk control', 'additional sustainability aspects' and 'socio economic assessment'.

Generally speaking, the SUNDS is based on conceptual models or frameworks (e.g., International Risk Governance Council 2017, 2005). It is a multi-criteria decision analysis tool, which integrates different criteria relevant for decision-makers. For each of these criteria, a theoretical model calculates how input variables affect output indicators, either by being directly designed into the system or linked to an external online module. The individual models used in the tool range from simple decision trees to complex models for (eco)toxicity, exposure and life cycle assessment (Malsch et al. 2018, 40). Yet, the 'maturity level' between these individual models varies (Interview 03). The SUNDS is built in a modular way with different analyses constructed in individual modules. Also, it includes a certifiable nano specific risk management and monitoring system (CENARIOS) as a stand-alone module (Marcomini and Hristozov 2017).

The SUNDS comprises two steps of varying complexity, tier 1 and tier 2. Tier 1 applies a qualitative, at times semi-quantitative, assessment of the product's

[26] https://sunds.gd/ (accessed 10 January 2021).
[27] http://www.nanocalibrate.eu/home (accessed 20 January 2021).
[28] https://www.biorima.eu/ (accessed 10 January 2021).

environmental, economic, and societal benefits and environmental, occupational and consumer risks (for a detailed description of individual modules of the tier see Subramanian, Semenzin, Hristozov, et al. 2016). It consists of an earlier tool, the LICARA NanoScan tool, which itself combines different tools[29] (van Harmelen et al. 2016, also see Subramanian, Semenzin, Hristozov, et al. 2016, Malsch et al. 2018). The LICARA NanoScan tool compares the costs of risk reduction to anticipated benefits for industries and small and medium-sized enterprises (SMEs) (Marcomini and Hristozov 2017). It sets out to check "supplier risks, competing products, market opportunities or making an internal risk and benefit analysis" (Zabeo, Keisler, et al. 2019, 2). It calculates environmental, economic, and societal benefits, as well as risk for public health and environment, occupational health, and consumer health. The tool allows combining data provided by the user and best guesses, and compares the performances of nano-enabled and non-nano-enabled products with a similar functionality (Malsch et al. 2017, 466). Moreover, it estimates the level of uncertainty: it offers "recommendations as to whether to proceed with nano-enabled product development, terminate development, or collect more information on specific risks and benefits" (Malsch et al. 2017, 466).

Tier 2 of the SUNDS (again, for a detailed description of the individual modules see Subramanian, Semenzin, Hristozov, et al. 2016) consists of risk control and socioeconomic assessment modules. The risk control module comprises environmental and human health (occupational, consumer and public) risk assessments to support the selection of risk management measures or technological alternatives for reducing risks. The socioeconomic assessment module "performs life cycle impact assessment, economic assessment, and social impact assessment" (Malsch et al. 2018, 41). The tool applies midpoints for life cycle assessment, and explores life cycle cost and social life cycle analysis methodologies for economic and social impact assessment (Malsch et al. 2017, 466, for a pilot study of social impact assessment see Subramanian, Semenzin, Zabeo, et al. 2016)

The SUNDS is able to consider user requirements. For example, for risk assessment, it allows using "test results from in-house tests and literature or to run exposure and hazard models connected to the SUNDS tool" (Malsch et al. 2017, 466). Moreover, the user can select between deterministic or probabilistic assessments to define risk management measures. In principle, the SUNDS may appeal to a range of potential users, from users and researchers in SMEs, industry, regulation, to academia and, to a lesser extent, civil society (Interview 03). However, project partners described its main target groups as SMEs, especially for tier 1, as well as industries, regulators, and insurance companies[30], although to a lesser extent (Interview 10; for a detailed analysis of stakeholder interests see Malsch et al. 2017).

7.5. Affording opening up and closing down

In this section, we look at opening up or closing down in an innovation context. To analyze the SUNDS tool, we deploy concepts of societal engagement, expertise and risk

[29] the Swiss precautionary matrix developed by the Swiss Government and Stoffenmanager Nano developed by TNO and ArboUnie (Netherlands) (for more information on these tools see Liguori et al. 2016) as well as NanoRiskCat, a conceptual decision-support tool funded by the Danish EPA. See also CaLIBRAte Webinar LICARA: https://www.youtube.com/watch?v=gUniJ6T_sLE&list=PLl8XHGDKVfG46cpM-zG8m4gsXtadkRQH2&index=3 (accessed 10 January 2021, min. 6:40 (ca.)).

[30] https://the SUND DSS.dais.unive.it/ (accessed 26 September 2020).

assessment, as well as the concept of affordances. Overall, computational modelling tools for risk governance encourage some understandings of risk analysis and management while discouraging others. Thus, we are interested how the SUNDS manifests certain ideas of risk governance through affording specific uses. To do so, we investigate three aspects, namely, how the tool (1) convenes stakeholder engagement and mobilizes specific expertise; (2) reproduces specific aspects in the conception of risks; and (3) affords different uses.

7.5.1. Societal engagement and expertise

Modelling tools like the SUNDS aim at integrating as many as possible aspects relevant for assessing and managing nano risks. Stakeholder engagement is supposed to ensure that all relevant perspectives are considered; to do so, the SUN project included scientific and research and innovation consultancy expertise ('R&I consultancy'). In addition, it engaged stakeholders from industry and authorities and identified further stakeholder needs to align the tool with users' needs (Malsch et al. 2017). Beyond that, SUN explored secondary uses of the tool for wider risk governance (Malsch et al. 2018).

For modelling in risk governance, the actors involved in the design of the models are essential. Tools like the SUNDS mobilize models from different scientific fields. This renders the actors' disciplinary backgrounds crucial. In general, modelling risks of nanomaterials predominantly considers the research fields of material sciences/physics, biology, and IT (Interview 07), drawing from disciplines like human and environmental toxicology, safety assessment, environmental sciences, or modelling in general. The SUNDS mobilized mostly scientific expertise common in risk assessment, like human health or environmental risks assessment and toxicology; modelling featured as a novelty. Thus, the tool solidifies risk governance as an interdisciplinary endeavor based on (natural) sciences; the composition of the SUN consortium reflects this understanding. Moreover, the SUNDS conceptualizes risk governance in a modular way: different kinds of knowledge are integrated in individual modules, which are, again, arranged according to overall risk frameworks (cf. International Risk Governance Council 2005, 2017). Hence, risk governance appears as multi-disciplinary expert-based effort, organized according to individual analyses in separate modules. The choice of a modular structure emphasizes the importance of stand-alone disciplinary expertise, despite the interdisciplinary aspirations of the project. Yet, this modular structure also allows for selectivity when applying the tool. Industrial stakeholders in particular acknowledged the option to actively select between analyses. For them, using integrated tools as one-stop solutions to assess and evaluate risks decreases transparency and increases black-boxing (Interview 02). This, in turn, implies a certain loss of control. To ensure a transparent communication of results, the dashboard of the SUNDS communicates risks and benefits of modules individually (occupational, environmental, LCIA, economic, social), in general or for individual life-cycle stages (except for social, which is only communicated in a general way[31]).

Developing the SUNDS relied on scientific and expert knowledge. This mirrors the aspiration of complying to established ways of evidence-based decision-making in nano risk governance. Here, traditionally, risk expertise remains very much confined. Thus, affording an extended range of actors or concepts induces fundamental shifts in risk

[31] Own observation of tool (24 October 2022).

governance practices (see e.g., Klinke and Renn 2021, Aven 2016, Renn 2015, Klinke and Renn 2014). In the SUN project, R&I consultancy expertise and stakeholders complemented scientific expertise and modellers to better tailor the SUNDS to potential application contexts. This consultancy expertise primarily considered aspects of usability, acceptance, or marketability, but also explored secondary uses and potential extensions of the finalized tool (see e.g., Malsch, Subramanian, Semenzin, Hristozov, and Marcomini 2015, Malsch et al. 2018).

Linking scientific work and application contexts, R&I consultancies, associations, or technical centers ensured the tool's 'suitability for real-world contexts' (Interview 01). More specifically, they conducted stakeholder workshops and interviews, considered external, i.e., non-technical, quality criteria, and enhanced the accessibility and acceptance of the tool. They included stakeholders and potential users early on for manifold reasons, in particular *" (a) to capture accurately, within the DSS [decision support system, author's note], problem formulations that are highly complex (including technical, managerial, regulatory and political components) and understood differently by various stakeholders, (b) to facilitate learning in an environmental management system through an environment of sharing and transparency and (c) to build trust in the output of the analysis through demonstrating its transparency and reproducibility"* (Malsch, Subramanian, Semenzin, Hristozov, and Marcomini 2015, 55, cf. Black and Stockton 2009). Therefore, stakeholder and user engagement allowed for addressing and iteratively resolving conceptual, definitional, and practical differences and helped to demonstrate the reliability of the tool.

Involving consultancy expertise illustrates two, partly contradictory, tendencies in the development of the SUNDS tool. The emphasis on *usability* supports risk assessment and evaluation to stay within traditional lines by addressing the needs of risk assessors and managers. SUNDS' tier 1, a rather easy-to-use tool, sets out to address a broad range of actors. In contrast, tier 2 requires more expertise, in particular regarding data and background knowledge about risk assessment (Interview 01). Therefore, it appeals to a smaller target audience and remained within more traditional lines of risk governance. Nevertheless, including expertise beyond a (natural) scientific core is a first step towards opening up the field. In principle, disciplines like psychology, sociology, industrial sociology, group psychology and behaviorism could be an integral part of risk governance, yet, until today, remain largely underrepresented (Interview 07). Hence, the efforts of the SUN project to broaden out its expert and stakeholder base may lead to further experimentation in risk governance in this regard.

To embed the tool in real-life practices, SUN engaged stakeholders in different ways. As part of the consortium, industrial research and production provided the basis for the project's case studies, i.e., nanomaterials for characterization, personal protection equipment, and data for specific analyses like lifecycle analysis of nano-enabled products. Moreover, they tested and validated the tool (Interview 05). Other stakeholder groups like SMEs, large industry, policy makers, authorities, insurance companies, risk assessors, and tool developers provided input on the tool's design and usability via a survey, semi-structured interviews, a stakeholder workshop, and a survey soliciting comparative weights (Malsch, Subramanian, Semenzin, Hristozov, and Marcomini 2015, Malsch et al. 2017, Subramanian, Semenzin, Hristozov, et al. 2016). In addition, stakeholders in the advisory board ensured trust for the tool (Marcomini and Hristozov 2017). Actor groups

with a potential critical stance, such as consumer groups, health activist or environmental NGOs, were considered too. They appeared as 'imagined actors', as they did not engage directly, neither as part of the consortium nor for stakeholder input. Rather, the tool included their stakes in a mediated way, e.g., via consumer exposure models. Project partners explained this with practical challenges, i.e., a mismatch between participatory requirements and stakeholders' working conditions:

> *"My role was to make sure that the tool targeted the real needs of policy makers and industry. So, I was supposed to do the stakeholder engagement. In reality, there was not so much interest from CSOs [civil society organizations], we tried to get them involved, but they have like very small budgets and not so many people"* (Interview 09).

As a result, their perspectives remain underrepresented in the tool.

Lastly, the SUN project reflected on the tool's role in broader societal contexts. Enabling mutual learning between actors for tool development was central to the project and stakeholder engagement set out to facilitate an in-depth discussion among a broad range of actors. Here, the SUNDS took on the role as a boundary object: project partners explored it to stir reflection, including a broad reflection on risk governance practices in international contexts (Malsch et al. 2018). The streamlined mandate of the project and the tool marginalized these considerations; yet, they show that the tool affords more variable uses than it was developed for. These considerations imply that the final tool only mobilizes a limited scope of risk-related knowledge and expertise, while they are actually more facetted. This became visible, when project partners called for stakeholder deliberation about risk-relevant, but hard to quantify aspects, like social aspects (cf. Subramanian, Semenzin, Zabeo, et al. 2016).

Overall, computational models are able to accommodate different expertise, perspectives, and data, and in turn afford inter- and transdisciplinary collaboration. This, again, affected the development of models. Yet, despite efforts to mobilize the tool for a broad range of stakeholders, it remained addressing specific actors. In the light of opening up and closing down, the tool afforded a specific composition of interdisciplinary actors in line with the overall scope of sustainable manufacturing. The SUNDS mobilized expertise by ensuring usability while deemphasizing a broader societal reflection, which remained outside the main mandate of the project. Overall, then, the engaged expertise was limited to expertise common in risk analysis, evaluation, and management.

7.5.2. Concepts of risk analysis

Risk governance orchestrates activities to evaluate and manage potential risks, for example when novel technologies are introduced to society. Usually, it is portrayed as distinct, yet mutually supportive steps (van der Heijden 2019, International Risk Governance Council 2005, 2017, Renn 2015, Isigonis et al. 2019). Risk governance determines risk through assessment, characterization, and evaluation, and suggests management measures (Hartley 2016, Hartley and Kokotovich 2018, 176). This is complemented by monitoring the process and constant communication between actors (van der Heijden 2019). Understandings of risk governance have been presented in a rather consistent way, yet shifted over time (Klinke and Renn 2021). However, there is still ample room to further development of overall frameworks and individual practices (see e.g., Aven 2016).

The SUN project mobilized the risk governance framework for sustainable manufacturing, combining risk and impact analysis with decision analysis (Malsch, Subramanian, Semenzin, Hristozov, and Marcomini 2015, Linkov et al. 2014). It understands risk governance as involving the actors, conventions, rules, and processes that are concerned with the collection, analysis, and communication of risk information. This is done to enable effective risk management together with other public and private policies (Subramanian, Semenzin, Zabeo, et al. 2016, 52, citing Renn and Roco 2006, 157). Moreover, risk governance considers *"the broader scientific and societal context within which risks occur in order to support decision-making that minimizes risks and maximizes benefits to stakeholders"* (Subramanian, Semenzin, Hristozov, et al. 2016, 89). Thus, it aims at active intervention, based on an embedded understanding of technological effects. Consequently, understandings of risk governance are strongly performative as they affect activities on a conceptual level, as shown for environmental risk assessment (Hartley, Kokotovich, and McCalman 2022), or the performativity of risk management (Themsen and Skærbæk 2018). In the SUN project, framing risk governance in terms of 'sustainability' inflicts a specific stance and advocates *"the integration of life cycle thinking, green nanotechnology, environmental and human health risk assessment analysis and management"* (Malsch, Subramanian, Semenzin, Hristozov, and Marcomini 2015, 54). Thus, the SUNDS opens up risk governance in several regards: it combines conventional risk assessment with life cycle analysis; it moves from risks towards sustainable manufacturing; and it shifts from a perspective of control to anticipation.

The first of these shifts concerns the methodological basis of SUN and the SUNDS, i.e., integrating risk assessment and life cycle analysis (LCA). LCA systematically analyzes potential environmental effects of specific products along the life cycle; risk assessment calculates the potential risk of individual substances as a combination of hazard and exposure. Integrating LCA shifted how to consider nanomaterials in relation to environmental, health, safety, and sustainability issues, namely, as 'nanomaterials in context' along the life cycle (Subramanian, Semenzin, Zabeo, et al. 2016). This is important as the use of nanomaterials in products, i.e., as compound materials and formulations, determines how users relate to nano particles in terms of proximity, exposure, and potential adverse effects. Thus, the SUN strived for a 'more realistic' evaluation of nanomaterials by assessing nano-enabled products instead of individual substances and particles (Subramanian, Semenzin, Hristozov, et al. 2016).

Likewise, computational modelling for risk governance constitutes an approximation to reality. This tends to disguise that both the conceptual basis and the execution of risk governance are malleable. On a technical level, the very process of integrating risk assessment and LCA rendered this malleability obvious. LCA is based on mass flows and is therefore time-dependent, while risk assessment draws from the concentration of substances. Accordingly, they use different data and analysis units. The computational models afforded this integration, involving science-based or practical choices. Yet, harmonizing these two approaches posed a crucial challenge to the SUNDS team:

> *"Let's say you talk about unit of analysis, like in one of the case studies, the copper-oxide-paint case study for example, the functional unit was to paint a square meter of a wall. That's what the LCA assesses. The risk assessment has no such unit. So, are the results compatible?"* (Interview 10)

The quote illustrates the technical difficulty of combining LCA and risk assessment, showing the malleability of analyses, as well as their increasing complexity. Thus, SUNDS conducts integrated risk analysis by adapting understandings of how to determine effects of nanomaterials, based on modifications of the underlying analytical approaches.

Second, the SUNDS shifts the very understanding of how to evaluate and handle effects of manufacturing and using nanomaterials. In general, the SUNDS constitutes a step towards a more comprehensive way of handling nanomaterials, illustrated by its overall objective: enabling transparent decision-making. Its analyses aim at ensuring that *"(a) risk and impacts of various nano-enabled products can be compared, (b) risk management can be based on an integrated view of various risks and impacts and the trade-offs between them, (c) risks and impacts of nanomanufacturing can be minimized based on technically and economically optimal means, and (d) uncertainty estimation and sensitivity analysis can indicate the strengths of evidence base and values on which decision-making is based"* (Malsch, Subramanian, Semenzin, Hristozov, and Marcomini 2015, 54-55). Thus, the SUNDS aspires to display evidence in a transparent way, as a foundation for responsible decision-making with regard to nanomaterials.

As indicated by the quote, both tiers of the SUNDS allow for balancing risks and benefits (Interview 03), and compare nano-enabled products to their conventional counterparts (Malsch, Subramanian, Semenzin, Hristozov, and Marcomini 2015, Zabeo, Hristozov, et al. 2019). Technically speaking, the consortium selected the multi-criteria decision analysis to balance risks and benefits. This is a large class of methods to evaluate alternatives based on analytical criteria and stakeholder preferences (for detailed descriptions of the approaches used within the SUNDS see e.g., Subramanian, Semenzin, Zabeo, et al. 2016). Although possible in principle, the SUN project refrained from assigning different weights to individual criteria since prior studies of the LICARA NanoScan did not confirm any impact on the final output (Malsch et al. 2018, 40). In any case, multi-criteria decision analysis allows moving from a solely risk-concerned to a more comprehensive approach of how to handle nanomaterials.

In the light of opening up, the SUNDS provides a fundamental shift from conventional approaches of assessing risks of nanomaterials towards sustainability, i.e. 'sustainable manufacturing' by including societal aspects like economic and social impact assessment next to environmental assessment (for details on the method see Subramanian, Semenzin, Hristozov, et al. 2016). This holds specific challenges: the missing common terminology and definition of 'the social', as well as the specificity of impacts for stakeholders (Subramanian, Semenzin, Zabeo, et al. 2016, 58). Regarding the first challenge, the tool's focus on 'sustainable manufacturing' affords a specific perspective on sustainability and requires indicators to classify as benefits or costs. This limits the range of social or economic indicators to a few categories. Regarding workers these are 'accidents', 'professional education', and 'training'; regarding the (wider) community they are 'tertiary education and training', 'employment', and 'research and development (R&D) expenditure'. Other social or economic, ethical or cultural aspects remain neglected since their impacts cannot be captured by (semi-)quantitative indicators or translated into benefits and costs. The project partners were well aware of this trade-off and proposed qualitative methods and stakeholder dialogues to complement the outlined indicators (Subramanian, Semenzin, Zabeo, et al. 2016, 67). Yet, compared to the overall affordances of the tool, these efforts remain marginalized.

The inclusion of socioeconomic analyses renders visible the innovation perspective afforded by the tool as they push towards a market introduction of products. To do so, the SUNDS serves to demonstrate the benefit of using a hazardous substance if it can't be adequately controlled or substituted in a specific context:

> *"[…] since we were using LCA for the environmental aspects, we were trying to align [with] the LCA for the economic parts and social LCA […] REACH - they have two modes, when you submit something for authorisation, […], you have to either show that you control the risks well or you show that you cannot control the risks, but then you have to show that this is a really important product for the economy and there is no substitute. And the social benefit of having this is unique, so we have no substitute, so we are going to go there even though there are some risks. […] we wanted to [use] this kind of thinking […], so we are not thinking in direction of: oh, there is a harm, let's take it out, but a little bit how to push the sustainability profile of your product forward"* (Interview 10).

By so doing, the tool cements an innovation paradigm: through widening its scope, the tool affords to weigh environmental and health risks against social and economic benefits to ease industrial innovation. Yet, the findings of the stakeholder engagement still supported earlier findings that found a "greater interest in risk assessment decision support than in a sustainability assessment which broadened the scope with environmental, economic and societal (risk-) benefit assessment" (Malsch et al. 2017, 478).

Within the consortium, the effort to extend the perspective on risks remained contested: not all stakeholders acknowledged the added value of including socioeconomic analyses, foremost because of the required amount of data, and the challenge to determine adequate and meaningful social indicators (Malsch, Subramanian, Semenzin, Hristozov, and Marcomini 2015, 66). This suggests that despite considerable efforts, the SUN project and SUNDS still followed conventional conceptions and indicators of risks. As a result, the tool's affordances remain limited to current risk-related practices, as project partners acknowledged: *"the SUNDS tool may overlook aspects that could be theoretically relevant, but are not currently taken into account by the decision-makers in companies and regulatory bodies"* (Malsch, Subramanian, Semenzin, Hristozov, and Marcomini 2015, 66).

Third, the SUNDS affords to expand towards innovation through 'safer-by-design' (SbD) (Malsch et al. 2018, 40). SbD is a concept that has become increasingly introduced in funding schemes by the European Commission (see Trump et al. 2018, 1). Rather than assessing a final product ready for market introduction, SbD aims at reducing hazards from the outset, sometimes supported by computational tools (Interview 07). SbD as afforded by SUNDS entails a comparison of different (nano)materials for the same functionality through functional assays and modelling, and guiding users towards strategies of safe product development (Interview 03). To do so, it includes sustainability data like LCA, social and economic impact assessments that go beyond traditional risk assessment, and risk management information (Malsch et al. 2018, 40). However, in the SUN project, SbD remained an add-on rather than a core activity:

> *"The SUNDs tool looked at risk control, […] but safe-by-design is saying you should substitute the hazardous chemical or not even use it or it's almost an [exception]. So SUNDs was saying: Did you manage to control your risks or not? And [then] give an answer to that. Safe-by-design is saying: we are trying to not even have the*

> *risks […] not only control them if possible. So we had something called S-b-D in the SUNDs project […] at the material chemistry level. […] For example, […] we had a nano-copper-oxide-based paint. How could you stop the release of the nanocopper in [certain] situations? Could you coat it with a coating? It was looking at that at the material chemistry level. Right now, what I am working on is: I don't even want to go there."* (Interview 10)

Regardless, project partners expected a bright future for SbD: follow-up projects continued shifting "the governance paradigm from risk management to prevention-based governance based on safe-by-design approaches" (Interview 03). Thus, integrating SbD in SUN implied a first move towards precaution, by assessing risks early-on and substituting hazardous materials instead of *ex post* control. This aligns with wider trends of anticipating consequences and enacting precaution in innovation early on. Thus, the SUN project strengthened precautionary approaches in assessing risk.

These three conceptual shifts show how the SUNDS reproduces a specific understanding of risk governance, i.e., sustainable manufacturing. At first glance, these shifts hardly emphasize the malleability and agency of modelling, despite rather extensive reflective work within the project. Instead, all these shifts promote rather 'realist' perspectives. Nonetheless, the SUNDS allows for opening up by integrating and affording rather unconventional aspects like sustainability or socioeconomic analyses. It aims at mirroring real-life exposure conditions through affording analyses of a *products* instead of materials and introduces precautionary perspectives through SbD.

Looking at the wider context, tools like the SUNDS are embedded in a narrative of inevitable innovation which determines their scope: literature predominantly predicts an increased use of nanomaterials. Moreover, the tool adheres to paradigms of calculability and measurability promoted by (ideals of) conventional risk assessment procedures, which complicates and slows down the tool's aspirations for opening up. Nonetheless, the affordances of the SUNDS may affect the practices of its users, as well as their underlying mental models of risk governance (Malsch et al. 2017, 477). By so doing, these practices could, again, inflict an opening up on a more fundamental level and eventually become translated in other areas as well.

7.5.3. Affording multiple uses?

The SUNDS was imagined to afford specific contexts of use: different actor groups voiced manifold expectations and requirements during its development, dependent on the respective purpose (Malsch et al. 2017, Malsch et al. 2018). First, the tool constituted either a basic research endeavor or a helpful tool for different application contexts. Accordingly, its requirements shifted considerably, leaving the SUNDS spanning between disciplines as well as scientific and real-life contexts. Second, actors imagined the tool to afford different understandings of regulatory compliance, from supporting the implementation of REACH requirements to enabling reflections on risk governance more generally.

When looking at the tension between basic research and application contexts, actors imagined different uses of the SUNDS. Some scientists and R&I consultancies saw it as a *decision-making tool* to orient stakeholders in concrete application contexts: *"The SUNDS tool is designed for an organisation's internal use in the context of a sustainability assessment and risk management approach that is compatible with preexisting*

regulation" (Malsch et al. 2017, 466, see also Malsch, Subramanian, Semenzin, Hristozov, and Marcomini 2015). Here, some considered industry and particularly SMEs without routinized risk assessment practices as the main target group (Interview 10). Others criticized the tool's limited usefulness, as it was either too complex to apply (for SMEs), or companies (in particular big industries) had their own risk assessment procedures (Interview 04). Besides industry, insurers were imagined as a potential target group, but showed limited interest in the tool because of the specific requirements of their field (Interview 10). Regulators, again, ensured regulatory compliance of the SUNDS, rather than using the tool themselves (Interview 10). This indicates that the conditions in which the tool is imagined to be embedded, like regulation or testing procedures, are negotiated elsewhere, e.g., in working groups of the OECD, EU or UN (Malsch, Subramanian, Semenzin, Hristozov, Marcomini, et al. 2015). As one interviewee put it:

> *"[…] you try to wield the tool for so many users and at some point, you realise… the insurance sector we could not help much. […] The regulators told us what would be acceptable scientifically and […] submission and stuff, but we ended up majorly building the tool for industry. The regulators were on board, but it was just very difficult bridging all of them"* (Interview 10).

As a result, the SUNDS turned out to serve a smaller range of audiences as originally imagined, and met challenges to provide targeted support for decision-making in SMEs or big industry.

In contrast, other scientists and research funding considered the SUN project and the SUNDS mainly as a *research endeavor*. In this understanding, the project and the tool contributed to a general methodological repertoire. Research funding in particular framed the development of the tool as 'explorative' research. Thus, they did not expect the SUNDS to address routine testing problems but defined the project's objective as promoting scientific and technical innovation:

> *"I mean it's science you're talking, that's where we are. So, we were not there to solve routine industrial or environmental problems. No. The new knowledge innovation is a master in the very first place. I will say so Horizon 2020 talks clearly, that's innovation, that's clear cut." (Interview 07)*

Eventually, this unresolved tension between scientific claim and practical implementation challenged the idea of a targeted tool development and implied a trade-off between the tool's specificity and user-friendliness. The tool afforded targeted support only to a limited extent, despite the remarkable efforts of the project in this regard, e.g., elaborated stakeholder elicitation. In any case, such projects and tools are supposed to ensure impacts of research and innovation in the real world, leaving sciences with a double burden (cf. Grieger et al. 2019).

Thus, the tension between 'routine-oriented' testing and 'innovation-driven' science points to an overall gap in aligning regulation and research (Interview 07). This tension has been flagged from the beginning of the SUN project (Malsch, Subramanian, Semenzin, Hristozov, and Marcomini 2015, 60). Throughout the project, requirements of innovative science remained at tension with routinized testing activities for policy-making and regulation, as illustrated by a workshop discussion about the regulatory acceptability of a specific approach: *"So far, no regulators have accepted the concept of probabilistic Risk Assessment. The output will be limited to academic papers, unless regulators adopt*

probabilistic risk assessment. The EC [European Commission, author's note] decision is their call" (SUN Consortium 2016, 6). Rather than concrete problem-solving approaches, tools developed in EU projects like the SUNDS constitute a 'pool' of methodologies for further research, i.e., a "feature of the field" (Interview 10). They serve as what Mansnerus (2013) called a "storage space of knowledge", where models stabilize links across disciplines (Mansnerus 2013, 272). Thus, while the SUNDS set out to meet needs of specific target groups, it ended up affording multiple but less targeted uses, spanning between different requirements. During the project, partners imagined broadening the tool's scope even more through additional affordances. Such propositions for future versions of the tool included a broader range of analytical pathways to be selected within the tool (Interview 02, Interview 07, Interview 09, Interview 10) and to provide additional analytic emphases like grouping or read-across (Interview 02), or ethical assessments (SUN Consortium 2016).

Regarding regulatory compliance, the different imagined application contexts implied a variety of ideas about how the tool complies to regulation. Overall, REACH constituted a central reference point for the development of the SUNDS. Therefore, the risk assessments of tier 2 are in principle in accordance with the REACH regulation (Malsch et al. 2018, Subramanian, Semenzin, Hristozov, et al. 2016, also Interview 01, Interview 02, Interview 03). However, the REACH annexes were only adjusted to nanomaterials in 2018 and enforced in 2020, i.e., after the SUN project was finalized. Hence, regulatory compliance remained vague: project partners considered REACH's effects on the SUNDS as ranging from guiding tool development (Interview 01, Interview 03), to affecting individual analyses, e.g., through the definition of nanomaterials (Interview 04), to not being closely linked to it at all (Interview 02).

For developers, SUNDS afforded compliance to REACH in two ways: fist, by using parameters and guidelines in individual models that align with REACH, like specific endpoints for toxicological analyses or standard exposure scenarios, and second, by contributing to risk assessment (Malsch et al. 2018). Regarding the latter, REACH leaves scope for interpretation, while the tool placed emphasis on innovation and scientific rigor (Interview 03). Consequently, the SUNDS affords novel research approaches, even if their regulatory acceptability remained unclear (Interview 10). One example is probabilistic risk assessment, which accounts for the variability of parameters for risk management measures (Malsch et al. 2018, 41). In the long run, in so doing, the SUNDS may steer risk assessment and management in new directions as probabilistic risk assessment is not yet established for regulatory testing. On the contrary, institutions like the European Chemicals Agency (ECHA) rely on authorized testing procedures and usually offer their own approved tools or refer to established procedures for risk assessment (Interview 02, Interview 04, Interview 09, Interview 10). Thus, industry considered SUNDS' affordances as going far beyond the scope of REACH; accordingly, fulfilling its extensive data requests had only little priority:

> *"These tools by far go beyond what regulation requires. Hence, first of all, it is no problem that these data don't exist. Of course, regulations could change; then, such data would be produced. Whether we need this or not – that's really another question." (Interview 02, translated by author)*

Ideally, industry imagined the SUNDS based on a clear and incontrovertible regulation, or authorized practice guidelines such as standardization and certification (SUN Consortium 2015a, 4). Hence, industry perceived the tool's data requirements as exceeding regulation and fulfilling these requirements as optional rather than compulsory (Interview 02). Likewise, including wider aspects of governance in the tool, like public concerns of consumers or CSOs, was no priority. However, companies considered them important, not least because of their potentially adverse effects on their reputation (cf. Malsch, Subramanian, Semenzin, Hristozov, and Marcomini 2015, 65). In contrast to industry, project partners found the SUNDS compliant to regulation. They stated that: "[i]n the case of the SUNDS system, this early user engagement has helped target the tool to needs of companies preparing dossiers demonstrating compliance with existing legislation" (Malsch et al. 2018, 47). This indicates a mismatch in perception between different actor groups: the tool afforded a certain compatibility with regulation, in particular REACH, but required data and analyses difficult to provide in (industrial) practice. Accordingly, some partners considered the tool an "academic exercise" (SUN Consortium 2016, 3). Thus, despite of, or because the tool affords a rather broad range of imagined applications, its use in (established) risk assessment procedures seems to remain limited (SUN Consortium 2016).

In addition to affording compliance to regulation, stakeholders explored the tool's potential to accommodate wider governance issues by considering business ethics or legal frameworks, or integrating legal or ethics-related modules (SUN Consortium 2016, 6). Also, they suggested to use SUNDS for exploring wider questions of policy and risk governance, in reality as well as hypothetically: either as part of the NanoSafetyCluster, or by applying the tool for adapting legislation (Malsch et al. 2018). Therefore, despite not affording risk governance in a broader sense, the SUNDS turned out to be a useful boundary object to engage stakeholders in dialogues (Subramanian, Semenzin, Zabeo, et al. 2016). Indeed, the risk governance aspect gained further importance in follow-up projects like NanoCalibrate and subsequent attempts to establish a nanotechnology risk governance council[32].

With regard to opening up and closing down, the SUNDS in principle provided potential to afford a broad range of imagined uses, i.e., to open up risk governance approaches. In particular, addressing wider issues of risk governance and considering the integration of a broader range of models aimed at opening up established ways of conducting risk analysis and management. However, the variety of imagined uses (application/science) and regulatory compliance (compliant/inspired by REACH) also illustrates the effect of insufficient closing down in innovation contexts, as living up to all expectations at once proved challenging in tool development.

7.6. Discussion: opening up through computational modelling

Our analysis shows different ways how a specific modelling tool exerts agency, namely first, through convening inter- and transdisciplinary collaboration (a core effort of the SUN project); second, through moving from risk assessment to sustainable manufacturing by adapting respective concepts; and third, by affording different uses and regulatory compliance. The SUNDS tool aimed for an integrated analysis of benefits and risks and

[32] Establishing a nanotechnology risk governance council was a core effort of the three EU projects Gov4Nano, NANORIGO, and RiskGONE.

raised expectations to allow "the user to consider all relevant aspects in decision making on nanomaterials and nano-enabled products" (Malsch et al. 2017, 466). Accordingly, it set out to open up the debate on risk governance through experimenting with novel approaches like probability risk assessment and socioeconomic assessment, and through manifesting a broad range of stakeholder perspectives.

In general, the design of the tool strengthens a scientific, positivist paradigm through delivering 'objective' results. It presents risks and benefits as predictable, measurable, and calculable. They are based on the assumption that effects of nanomaterials or conventional chemicals can, in principle, be measured and the resulting risk can be quantified and controlled, a perspective that has frequently been criticized by STS and risk research (see e.g., Miller and Wickson 2015, Nel et al. 2011, Hartley and Kokotovich 2018). Computational modelling constitutes a suitable methodology within this paradigm as it caters to demands for quantification and numbers that are perceived as rational and objective. As one interview partner put it: "first we need to be able to quantify risk… identify risk, quantify it and then do something about it" (Interview 07). Against this background, tools like the SUNDS explore how to open up these perspectives, at least to some extent. Here, shifting the perspective towards sustainable manufacturing was one example. However, at the core, they still adhere to a decision-making paradigm that is ideally based on quantitative data:

> *"Highly quantitative researchers, even though they know their own tools are models and they depend on data and assumptions, they will look down on something that's so qualitative [i.e., the screening approaches in tier 1] for example" (Interview 10).*

While the tool allows a qualitative screening for practical purposes, the more sophisticated analyses of tier 2 afford a quantitative paradigm of assessing risks compliant with regulation. Thus, qualitative approaches were suitable as a preliminary choice when quantitative approaches were deemed inappropriate or data was lacking[33] (Malsch, Subramanian, Semenzin, Hristozov, and Marcomini 2015, also see the screening of nanoproducts in tier 1 of the SUN DSS, Subramanian, Semenzin, Hristozov, et al. 2016, 2). For the project, making impact measurable constitutes a key purpose of risk governance:

> *"Semi-quantitative and qualitative approaches, while informative about stakeholder intentions and judgement on social impacts, do not provide an assessment of actual social impacts that have occurred through the value chain. Indeed, a key purpose of risk governance is to align perception of impacts with actual measured impacts […], and thus there is the need to incorporate for both factors in the implementation of risk governance"* (Subramanian, Semenzin, Zabeo, et al. 2016, 52).

Yet, quantification requires data: rather than a lack of available computational models, unavailable, non-accessible and/or poor-quality data limits current modelling activities (Interview 01, 04). Therefore, the extent to which the SUNDS actually succeeded to provide quantitative assessments remained under discussion (SUN Consortium 2016, 3). Nonetheless, it aimed for 'clear' and 'objective' scientific results as a neutral basis for

[33] With regard to management, EU authorities, in absence of evidence use worst case scenarios to determine risk assessment (Malsch, Subramanian, Semenzin, Hristozov, and Marcomini 2015, 64).

decision-making, as stated in one of the project's stakeholder dialogues: *"The tool may be used in different regulatory and legal context[s] where conflicting interests play a role. This calls for science-based outcomes of the SUNDS tool"* (SUN Consortium 2015b, 4-5). As this quote shows, results of tools like the SUNDS are imagined to remain unaffected by wider political implications. This supports the argument that risk assessment is usually depicted as retracting from any kind of political (i.e., socially contestable) activity (Hartley and Kokotovich 2018). Attributing values like 'universality' and 'objectivity' to the results of the SUNDS suggests that they remain independent from regulatory contexts as well as particular interests of actors.

In general, the debate on nano risk governance is highly scienticized. Accordingly, SUNDS effortlessly follows the hegemony of the scientific framing of risks that is common in evidence-based decision-making. By emphasizing sustainable manufacturing, the tool backgrounds a broader scope of risk governance, as called for by risk research (e.g., concern or safety assessment, see Klinke and Renn 2021). However, project partners have reflected on these limitations (Malsch et al. 2017, Malsch et al. 2018, Subramanian, Semenzin, Zabeo, et al. 2016).

Overall, the tool perpetuates common characteristics of risk assessment and modelling. By foregrounding (natural) scientific input, risk modelling relies on few specific disciplines. Despite numerous attempts to broaden understandings of risk governance, the actor forum remained relatively narrow: next to science, IT, and translational expertise, involved stakeholders mostly came from industry and regulation. The tool's structure organized the project's expertise in interlinked modules where each discipline contributed to specific analyses. To present assessments in such a modular way is an intentional choice that emphasizes stand-alone disciplinary expertise and usability over integrated approaches to modelling. Thus, the tool not only stabilizes common expertise-based understandings of risk assessment and analysis, but highlights the independency, transparency and traceability of specific inputs in the overall process.

Generally speaking, risk governance builds on multiple sources of knowledge (van der Heijden 2019, 2). Literature has pointed out that risk governance, including risk assessment, hardly accommodates wider social pluralism and, consequently, marginalizes the lay public and alternative expertise (Renn 2015, Klinke and Renn 2021). Accordingly, scholars have requested to better indicate and foster engagement in risk assessment procedures to ensure transparent, just and inclusive decision-making (Hartley, Kokotovich, and McCalman 2022, cf. Hartley and Kokotovich 2018). Through engaging stakeholders early on, the SUN project took a step towards normalizing opening up in this context. Yet, existing blind spots may still remain since the SUNDS builds on existing approaches of addressing novel technologies (cf. Malsch, Subramanian, Semenzin, Hristozov, and Marcomini 2015, 66).

To open up tools like the SUNDS, reflecting their affordances is crucial as computational tools easily manifest and sustain underlying assumptions and concepts. Such a reflection is all the more important as computational modelling is still rather new and under development (Malsch, Subramanian, Semenzin, Hristozov, and Marcomini 2015, 68). Thus, while already common for some tasks, their application for others is unlikely, *"because the regulators and stakeholders currently do not use tools [in context of wider risk governance dialogues, author's note]"* (Malsch et al. 2018, 47). Accordingly, the field tends to rely on human expertise and deliberation instead of technical approaches

in decision-making. Reasons for this are beyond the scope of this chapter but may concern the high societal and environmental stakes and potentially far-reaching consequences of how risks are conceptualized. Consequently, broadly introducing tools like the SUNDS would not only imply a shift in individual analyses or frames, but inflict a wider shift in regulatory and stakeholders' practices. Against this background, assumptions of computational tools like the SUNDS, or any other tool for that matter, need to be reflected particularly carefully.

7.7. Concluding remarks: opening up the affordances of risk governance tools

Looking at the affordances of the SUNDS in the light of opening up and closing down rendered obvious the power of pre-framing through the wider scientific, regulatory, and nano-related discourses. The tool does not afford open anticipatory activities; broader questions of governance are negotiated elsewhere and, eventually, become translated into the tool. Largely, the SUNDS draws from established understandings of risk assessment and management, with individual attempts of opening up, i.e., by affording additional analyses suitable for sustainable manufacturing. As it fosters an ideal of quantitative assessment, the SUNDS can be considered to reinforce the divide between scientific-technical approaches and wider framings of assessing and handling technologies, a divide addressed since the early days of nanotechnologies (cf. Bröchler 2007).

However, in this chapter, we outlined a few indications for potential shifts and opening up: most notably, tier 2 of the tool afforded an approach for quantitative risk assessment and control with the possibility to conduct a socio-economic assessment. By aiming for an easy-to-interpret tool, it provided approaches of assessment and management of nanomaterials for non-experts; however, to which extent it succeeded is up for debate. Moreover, individual publications explore the tool's potential to contribute to a broader reflection on risk governance practices (e.g., as boundary object between actors in international governance, see Malsch et al. 2018). While not core to the project, this work indicates that the tool may afford more variable uses than currently considered, and emphasizes the exploratory quality of the SUN project with regard to opening up of the debate on risk governance.

Overall, the SUNDS and the SUN project indicate an increasing importance and willingness to consider concepts of responsibility more specifically in research fields and professional discourses (like concepts of R(R)I, see von Schomberg 2013, Owen et al. 2013, Owen, von Schomberg, and Macnaghten 2021). In literature, nanosubstances served as a showcase for new, reflexive approaches of anticipatory governance (cf. Åm 2015). However, similar ideas have been applied to the nano field long before concepts like R(R)I entered the stage. This illustrates the impact of discussions on responsibility in particular in the context of the nano discourse, which draws from long-lasting debates on social responsibility, technology assessment or responsible innovation (Shanley 2021).

The SUN project explicitly engaged with the R(R)I concept, as indicated by the extensive stakeholder elicitation and the engagement of R&I consultancy to reflect the development of the tool and its role in wider risk governance. Risk scholars have long emphasized advantages of stakeholder engagement (Renn 2015, Klinke and Renn 2021). However, there are indications that these shifts are not easily implemented in governance practice. The SUN project aimed at normalizing increasing reflection and anticipation, as

the consideration of safe-by-design in the tool design indicates, even if it does not yet live up to its full potential.

Overall, endeavors like the SUN project strengthen tendencies to overcome a fragmented understanding between innovation (research, economics) and protection/risk (environmental and human health, social affairs, etc.). This enables more integrative stances towards sustainability. This, again, contributes to re-conceptualizing understandings of risk governance selectively, and mirrors tendencies of opening up technology. Looking at the affordances of computational tools in this regard helps to bring out and distinguish between hopes for opening up and its actual way of materializing in the virtual.

Part III

Analyzing opening up and closing down and concluding remarks

8. Opening up and closing down technologies: dynamics at play

In this thesis, I looked at the phenomena of opening up and closing down to better understand the governance mechanisms of emerging technologies through participation and societal engagement. I reviewed the debates on the democratization of technology in Part I; here I concluded that inclusion is an admirable goal but not a straightforward matter. The twin concepts of opening up and closing down address the paradox of unlocking participation: seeking to improve the development by adding more voices consistently ('opening up') while acknowledging that any development needs some closure, too. In Part II, I investigated the various manifestations of opening up and closing down in three cases of emerging technologies and societal engagement. I studied myths in neuroenhancement (Chapter 5), moves of civil society organizations in synthetic biology (Chapter 6) and computational tools for assessing risks in nanomaterials (Chapter 7).

In this last part of the thesis, I take stock of the empirical findings and conclude what these contribute to the question of participation and societal engagement in emerging technologies, theoretically and practically. The conceptual vehicle to exercise this task are the three dimensions of opening up and closing down: social, epistemic and normative. In this chapter, I will investigate the interaction between opening up and closing down empirically, by first looking at the individual case studies (section 8.1), and then comparing the dynamics along the three dimensions (social, epistemic, normative) playing out in the cases (section 8.2). The first analytic move emphasizes the characteristics of each case study, while the second allows a generic reflection on the relation between opening up and closing down. Lastly, I will discuss what the mechanisms of public sense-making, dialogue, and affordances reveal about opening up and closing down and the question of unlocking participation in general (section 8.3).

8.1. Opening up and closing down technologies through participation and societal engagement

This section provides a case-by-case analysis of opening up and closing down in relation to the different technologies. By so doing, it also follows the characteristics of different moments along the innovation stream.

Earlier, I addressed the problems of using the innovation stream metaphor (section 2.3.2). Despite its misleading and unfortunate suggestion that innovation can neither be stopped, nor that its direction can be changed, the metaphor of a 'stream' is still useful as it highlights the temporality of innovation. There is always an 'earlier' and a 'later' and that matters for questions of participation. Maybe for that reason, the innovation stream metaphor is omnipresent in the literature on participation and societal engagement, for instance in the fashionable term of 'upstream' engagement. To do justice to this basic notion of an 'earlier' and a 'later', I selected case studies that presented different 'stages' of technologies (and the respective discourses) alongside an innovation stream (see section 4.2). For these reasons, I will continue to use the innovation stream metaphor as a rhetorical figure without accepting its reductionist ideas of directed innovation.

8.1.1. Myth formation as public sense making in the context of neuroenhancement

The first case study addressed a mechanism of public sense-making: it emphasized how unfamiliar technologies become familiarized in public debates by mobilizing the concept

of 'technology myths'. The study was based on empirical data from engagement activities aiming at discussing the governance of neuroenhancement (NE) and elaborated on the mechanisms through which public myths emerge. The study reviewed how, in general, myths fulfill a specific societal function and are historical and ahistorical structures at the same time. *Technology myths*, we concluded, transfer meaning via so-called technology comparators. Here, myths create a specific picture of a technology by selectively highlighting some of its traits while omitting or marginalizing others. Technology myths arise easiest at an early point of technology development when real-world applications of the technology at stake are still lacking. In such conditions, their traits usually are contested and cannot be assigned unanimously.

Narrative structures like technology myths allow insights into how public perspectives about technologies are formed. The study showed how narratives are performative and eventually manifest in different ways, like in stakeholder deliberations or technical artefacts. In this case study, opening up and closing down relate to these narratives and their function in public sense-making: opening up means to consider a range of technology myths consistently, i.e., to offer different interpretations of complex technical issues like NE in different ways. In turn, these interpretations affect how NE (or other emerging technologies) are perceived down the road. Looking at these mechanisms more in-depths, I analyze processes of myth formation and public sense-making with regard to my three analytic dimensions, social, epistemic, normative.

Regarding the *social* dimension of opening up and closing down, it is helpful to look at its empirical set-up. In the run of the NERRI project, a colleague and I conducted four focus groups with high school students and teachers in two schools in Vienna, Austria to learn about their perspectives on NE early upstream (also see Chapter 4). Thus, the case study's set-up included calls for involving multiple actors and perspectives in STI governance, especially those marginalized in expert deliberation, as emphasized under R(R)I (cf. Bauer, Bogner, and Fuchs 2021). Engagement activities are supposed to enrich the debate at hand by generating public deliberation as input for STI governance. Thus, the case study mirrors the tendency in STI governance to acknowledge societal pluralism by broadening out the actor base of the debate on NE in a selective way. By only engaging the lay public, it enhanced the agency of a specific actor group. Yet, it remained narrow in terms of actors that it addressed: myths-making of actor groups like policy makers, scientists, or developers only served as a vague contrast for public myths-making. However, overall, the case study enriched the debate on NE by considering public perspectives. Projects like NERRI assume that a broad(er) actor base early-upstream leads to an open debate later on as the actors involved create space for (re-)negotiating the terms of technology development. Thus, continuously involving more actors in a STI debate is supposed to result in a range of public myths, opening up the overall discourse on NE, a premise that by its very nature can hardly be tested.

The case study addressed opening up of the *epistemic* dimension in two ways. First, opening up showed as consistently introducing different interpretations of NE. Myths considered NE as drinking coffee, a harmless daily routine, or as consuming drugs, an illegal social practice, and entailed different evaluations of these practices. By mapping the scope of perspectives, myths contributed to opening up in that they visualized a plurality of perspectives. Second, opening up related to the adaptability of myths to social contexts over time. For example, myths align interpretations between technologies, or

technologies and their application context. In my case study, NE constituted a daily routine (drinking coffee) or an illegal practice (taking drugs). Both entailed different evaluations of risks and health impacts, distributional fairness, or moral scruples, i.e., whether NE was perceived as harmless stimulant or a sketchy practice. Therefore, opening up in public sense-making addresses myths themselves: to remain meaningful, myths need to remain adaptable to changing social contexts.

For most parts, however, myths close down the debate. Anthropologists remind us that myths provide explanations and interpretations of difficult issues (see Chapter 5). In our case, we saw that they constitute a narrative shortcut to comprehend complex unfamiliar technologies by selectively transferring characteristics from one technology to another. As a way of public heuristics, they hardly rely on technical knowledge or data. Instead, myths capture the imagination, the "if-and-when" aspects of technologies. Consequently, they tend to close down debates by offering plausible narratives for anchoring individual perspectives. Myth formation molds epistemic aspects into specific world views, expressed in narratives. Therefore, they strengthen tendencies of closing down debates as they only selectively include new interpretations. Moreover, myths persist in a non-transparent way and thus, they easily become performative in wider technology debates, potentially inducing their closing down in the long run.

The tendency of myths to close down debates makes visible how closely the *normative* and epistemic dimensions converge. Myth formation brings familiarity to unfamiliar situations; whether this familiarity exists in technical terms is secondary. People use technology myths to provide compelling and comprehensive narratives that reduce uncertainty and insecurity. Technology myths suggest a foreseeable future since they rely on interpretations of established technologies. Due to their pervasiveness and persistence, they shape present and future debates alike. Technology myths colonize the future by transferring present-bound assets to discourses of future technologies. Whether NE is interpreted as 'drinking coffee' or 'drug abuse' not only affects the future of NE, but also of other (similar) technologies. Thus, transferring features from one technology to another via technology comparators can found new myths, e.g., based on established NE practices. This mechanism is best illustrated by the example of synthetic biology, where narratives strongly relate to computational sciences or prior practices of genetic engineering (see Chapter 5 or 6, respectively). Thus, the study of myth formation shows how narratives span between different technologies and illustrates how technology futures are easily colonized through narrative structures. This phenomenon has been extensively addressed by TA practitioners and STS scholars, especially in the context of vision assessment (e.g., Frey et al. 2022).

In sum, while early-upstream deliberation and mechanisms like myth formation are imagined to contribute to setting the stage for STI, in particular under R(R)I, they also do more. Here, I present three interesting findings: that topics of public debates strengthen the colonizing effects of myths; that myths transform technical debates into debates easier to grasp for public actors; and that the normative consequences of myths in early upstream engagement must not be underestimated.

First, in general, *broadening out* actor bases by including specific actor groups, i.e., the public, is supposed to eventually open up the debate on NE. Yet in context of emerging technologies scholars have criticized invited engagement, i.e. initiating a public debate from scratch, to induce topics that would not raise interest on their own (e.g., Delgado,

Kjølberg, and Wickson 2011, see section 2.3.3). If taken up by public discourse, these topics hog attention and shift public priorities; thus, they become performative and may colonize the future in the long run. In this way, they are part of the discussion on 'speculative ethics', which Alfred Nordmann (2007) has criticized for diverting resources from transformative technologies of the present. Hence, early upstream engagement brings a threat of inflicting a public debate that does not emerge from public affectedness directly. For my case study, the reproach of having mobilized the public out of the blue is justified considering the missing public discourse on NE at that time.

Second, this case study provided interesting insights on opening up STI governance debates as it allowed to *reframe the issue* at stake. Participants transformed technology-based concepts, i.e., debating the pros and cons of NE, into aspects closer to their everyday experiences, like performance pressure at work, or questions about the quality of life altogether. Moreover, participants discussed concepts like competition and (un)fairness, or perceptions of naturalness and artificiality of NE practices. Thus, despite their closed-down nature, myths can be useful in public sense-making by transforming technical discussions into easier-to-grasp concepts related to social practices. Here, allowing participants to reframe the issue at stake is central to opening up the debate. The distance of early-upstream engagement to actual decision-making contexts in governance or industry facilitates this considerably.

Third, this case study illustrated the importance of reflecting on the normative dimension, since myth formation early upstream emphasizes *normative over epistemic* aspects. It does so for two reasons: first, because factual knowledge is usually slim early upstream, and second, because of its focus on *public* sense-making instead of technical visionaries. Yet, as I will argue later, the importance of the normative dimension is not restricted to early upstream engagement.

In short, involving the public as in the set-up of this case study constitutes an attempt to open up debates in STI governance. With regard to opening up, the explanatory function of myths may help to make technical issues more accessible for the public. Yet, the tendency of myths to colonize the future in a non-transparent way, and therefore to close down debates in the long-run, prevails. Hence, reflecting on the normative orientation of engagement early upstream is fundamental. In this case study, TA practitioners took on this role by intervening as a "myths buster". They aimed at grounding the debate and providing technical specifications to support reflection on NE's embedding in wider societal issues. Thus, TA provided a 'reality check' on NE, i.e., distinguished between (currently) technically achievable applications and utopian or dystopian narratives. In addition, mapping the range of technology myths would visualize the plurality of perspectives and allow following dependencies of narratives. By so doing, TA has contributed to opening up the debate.

8.1.2. Investigating the involvement of civil society organizations in dialogues on synthetic biology

In the second case study we compared different settings of CSO engagement and analyzed their actor roles, formats, and framings in relation to synthetic biology. The first setting was a public protest against household products that (potentially) contained synthetic biology components to substitute palm kernel oil; the second was triggered by this conflict and featured an invited multi-stakeholder deliberation process; the third was organized under the premises of upstream engagement of R(R)I. The settings thus ranged from early-

upstream engagement to downstream reactions to ready-for-market products, contrasting invited engagement with other forms of engagement, i.e., protests as explicit political activity to alter decision-making on a specific topic.

This case study compared different forms of dialogue and looked at how *different conditions* shape and are shaped by CSO engagement. Opening up related to a range of different narratives underpinning various perspectives, which affected how emerging technologies were perceived and assessed, and thus, shifted the scope of established practices.

Socially speaking, it is important to note that CSOs participated in all three dialogues, albeit in different roles, and broadened out the range of actors in public debates on synthetic biology. To explore the boundaries of CSOs in multi-actor dialogues, we were particularly interested in the role of CSOs that were critical towards synthetic biology and acted as advocates of public interests. Due to their limited resources, CSOs hardly engage in cutting-edge issues like synthetic biology; thus, only few CSOs were involved in the debate altogether. If they were, it was often because they had already been active against genetic engineering: this debate provided framings and heuristics that CSOs mobilized again with synthetic biology. Whether CSOs perceived their engagement as fruitful varied between engagement formats. In protests, a range of CSOs called for resistance against a particular company; here, no other actors were actively involved. In contrast, invited engagement included a broader range of actors from researchers and a broader range of industry to the public. However, the participation of CSOs remained restricted to a 'gatekeeper' role to the wider CSO community. If formats were considered open, CSOs accepted this role and became representatives of a more general CSO perspective. If not, for example when CSOs suspected formats to be pre-framed, they also perceived the strategy of involving 'gatekeepers' as insufficient, i.e., as an additional narrowing and closing down of the debate.

When focusing on *epistemic* aspects, I saw many shifts too. How to conceptualize synthetic biology practices turned out to be particularly crucial. Whether a specific practice was defined as synthetic biology affected the concepts of risks. Industry, for instance, considered the practice as conventional biotechnology, which rendered it well-assessable by established practices. In contrast, CSOs characterized it as novel and artificial biology, and called for new procedures to assess and control not yet well-assessed risks. Eventually, the discussion reached a dead-end and the practice was put on hold.

However, CSOs succeeded in broadening out the range of issues to appraise synthetic biology as they introduced new aspects in the debate. In all three engagement settings, CSOs emphasized marginalized aspects of synthetic biology like fairness in or ethics of production, which stimulated reflection and opened up the debate. One such issue was ensuring the livelihood of farmers in the Global South instead of promoting a high-end technology solution favoring innovation in the Global North. However, balancing perspectives and reaching an understanding about the matter at hand turned out difficult in all engagement settings. Thus, actors mainly continued broadcasting their own perspectives instead of entering into a "balanced dialogue" as promoted by R(R)I.

Regarding the *normative* dimension, I concluded that framings introduced by actors indicated tendencies of opening up and closing down. Most prominently, framings of sustainability shaped the debate. Some actors (CSOs, but also industry) promoted a sustainable future including a potential for synthetic biology applications. Thus, they

promoted a rather 'weak' understanding of sustainability, emphasizing technical solutions to environmental problems. More critical CSOs aimed at a more fundamental opening up of the debate. Instead of considering synthetic biology as part of a sustainable future, they preferred a more radical 'green' life-style altogether. They either promoted alternative technological solutions for substituting palm oil or rejected technical fixes to global problems altogether. Therefore, underlying conceptions of sustainability shaped the normative consequences of synthetic biology. At the same time, while individual perspectives closed down, CSOs broadened the overall range of options on the topic.

This case study provided vivid examples of different technology appraisals by various actors. Moreover, it showed *how negotiations appear under different circumstances*. For example, a virulent opposition to synthetic biology was accommodated by settings that provided framing sovereignty to CSOs (e.g., protests) or that were flexible enough to allow for different framings to co-exist (e.g., upstream deliberation). In decision-making contexts, some actors (industry, organizers) considered critical CSOs to hinder invited dialogue due to their limited willingness to accept compromise. These actors expected individual settings to align with framings of wider governance: emphasizing economic benefits, commercialization, or social progress, these framings eventually accumulate to a meta-perspective of risk and control that defines current STI governance (see interviews, and from literature Marris and Calvert 2020). In this case study, opening up therefore refers to providing a space for renegotiating the issue at stake and for considering a broad range of perspectives. This, however, depends on the setting's role in relation to wider governance. How a dialogue is conducted affects whether actors involve themselves consistently, and consequently influences the opportunity for opening up and closing down.

In the debate on synthetic biology, CSOs aimed at exceeding established ways of risk assessment. Their success depended on their way of argumentation and how they were involved in dialogue. Invited engagement as promoted under R(R)I requires actors to balance their own viewpoints and interests against the interests of others, allowing for compromise. As a result, when CSOs fundamentally disagreed and closed down their positions, other actors tended to consider them a challenge. Thus, in invited engagement, they were either likely to be dismissed or perceived as stalling the debate. In uninvited engagement, however, their strategy proved fruitful: the production of the algae oil under discussion was put on hold.

Engagement formats played a considerable role for opening up or closing down. Early upstream engagement provides space for open debates; yet its impact on wider decision-making remains unclear. The more decision-oriented the engagement setting – at least in the eyes of the actors involved – the stronger the tendency to close down the debate, both in terms of actors engaged and in perspectives considered. In general, invited engagement failed to involve closed down positions like fundamental oppositions. Nonetheless, these positions broadened out and opened up the overall landscape of perspectives on synthetic biology, and eventually enforced an alternative closure of debate. Thus, they established real-life consequences for future synthetic biology applications. Consequently, a broad range of different engagement formats may be best to give voice to different perspectives in different ways and to support opening up.

Finally, this case study demonstrated different roles of technology assessment in STI. Some TA actors were involved in one of the projects and steered dialogue on synthetic

biology early upstream. Yet, TA also appeared in an analytical role: other TA actors analyzed the debate in public events on a meta-level. Distinguishing between an interventionist and an analytic role of technology assessment was productive as the latter provided further insights into the dynamics of the case study; at the same time, it avoided overburdening one single actor with – potentially contradictory – roles.

8.1.3. Exploring computation modelling for nano risk governance

The third case study addressed the affordances of the SUNDS tool, a computational modelling tool for sustainable manufacturing of nanomaterials. It was the main outcome of the research project SUN funded under the FP7 of the European Commission. Here, we reconstructed how the tool affords actor constellations, concepts, and the imagined contexts of using the tool, in particular in relation to R(R)I. By so doing, we explored virtual manifestations of discourse in the context of computational modelling. Generally speaking, *affordances* limit the way how (virtual) artifacts are used, i.e., close down discourse through material conditions. They perpetuate specific understandings of issues at stake, like risk or sustainability, and accommodate potential user choices. In this case study, opening up relates to the (increasing) range of affordances that the tool allows for, and the shifts in discourse that they imply.

With regard to the *social* dimension, I showed that different actors were involved in developing the tool: next to researchers from various disciplines, the project also included stakeholders; this mirrors a rather recent trend in risk governance (Renn 2015, Klinke and Renn 2021). Over four years, the SUN project gathered broad input on risk management and took a step towards opening up by continuously involving these actors in inter- and transdisciplinary collaborations and feedback loops for the tool. However, the range of actors was limited to researchers and experts of specific disciplines and certain professional fields. Some stakeholders, like industry, policy makers, or insurers, engaged as part of the consortium or through engagement exercises, while others, like NGOs, consumers, or citizens, were not involved. This narrowed down the scope of the project to a few well-established perspectives on how to determine risks and benefits. The tool affords these perspectives through the respective analyses and draws from expertise that is common in risk assessment, from environmental exposure to toxicology. Additional aspects, like consumer perspectives, are translated into models aligning with the overall agenda, e.g., consumer exposure models.

Next to technical and analytical expertise, the project included non-technical experts like agents for responsible innovation (R&I consultancies). They mostly conducted stakeholder engagement to ensure the usability of the SUNDS. In addition, they also encouraged broader reflections on how to apply the tool in wider governance debates, and by a broader range of stakeholders. However, these aspirations remained side-lined compared to the main mandate of the project.

Originally, developers imagined the SUNDS to target a broad range of needs, from those of policy makers to industrial stakeholders. Yet, in reality, the main target audiences remained risk assessors and researchers, at least for the tool's more elaborate stages due to its data requirements and its emphasis on risk analysis. Actor involvement closely interrelates with imaginations or narratives of contexts of use. The tool allows users to adjust it to different professional contexts, but favors scientific and expert approaches to address risks. Consequently, the tool's efforts to broaden the range of actors involved in development and use remained limited.

Epistemically, the SUNDS affords conceptual shifts that mirror the scientific advancements in the field, i.e., to make assessments of nano risks more 'accurate' and 'realistic'. These shifts addressed three aspects in particular: assessing materials in consumer and industry products instead of pure substances or free particles; considering the life cycle of nanoproducts from synthetizing the materials to the disposal of the products; and applying concepts like 'safe-by-design' to reduce the use of hazardous substances from the outset. Each of them indicated a way to broaden out and open up risk assessment procedures over time.

In this case study, computational modelling constitutes a rough approximation to reality, following a positivistic perspective. Thus, the SUNDS reproduces ideals of risk governance based on quantitative risk assessment, but affords to move beyond a solely risk-based scope. Instead, it aims to foster 'sustainable manufacturing', a specific concept of governing nano products. The tool incorporates risk analyses like exposure models, hazard characterization, or risk assessment models, as well as a socioeconomic impact assessment module. Yet particularly the latter challenged the aspiration of conducting quantitative assessments: societal impacts like cultural or ethical aspects proved difficult to measure. Therefore, project partners recommended qualitative methods and stakeholder dialogues to enrich the debate on these issues (Subramanian, Semenzin, Zabeo, et al. 2016). Extending the tool in this way selectively opens up its scope, albeit to a limited extent.

The *normative* implications of the SUNDS tool were salient, too. The SUNDS affords analyses that are at least broadly compliant with regulatory requirements. It promotes the ideal of a regulation based on quantitative assessments with semi-quantitative and qualitative approaches serving as an approximation until quantitative data becomes available. Yet, actors promoted various imagined uses of the SUNDS, and implied different ways of developing the tool. Most prominently, some project partners and stakeholders considered the tool as an instrument for industrial risk management. Other project partners and actors, like research funding, saw it as scientific endeavor, i.e., experimental research, supposed to contribute to an overall knowledge reservoir. This resulted in a less defined role for the tool. Accordingly, tool development had to balance the tension between the requirements of scientific accuracy and pragmatic manageability.

Overall, this case study illustrated how *computational modelling tools afford specific ideas and values*. The SUNDS tool configures epistemic and normative aspects, as well as the underlying narratives that they perpetuate. These narratives reveal how the tool affords handling risks and sustainability in the context of manufacturing. Opening up the SUNDS by introducing broader concepts like sustainability, anticipation, and precaution paved the way for further advancements. However, the scope of the final tool afforded only a selective extension of risk assessment and management in order to remain manageable and applicable for industry. Thus, the tool allowed to open up risk perspectives, but to a limited extent. However, due to its modular structure the tool could in principle adjust to new concepts; I consider this as an opportunity for latent opening up. For example, project partners discussed whether to integrate legal conditions or ethical aspects into the tool. This was dismissed for the current version because of the high contestability of these aspects along the value chain; however, the discussion eventually continued (see Malsch et al. 2020). These imagined affordances opened up the tool, by shifting the scope of the tool as well as the actor groups involved in its further

development. Compared to conventional risk analysis, the current version already enabled new affordances by broadening the emphasis from risk to innovation, and invited wider debates on risk governance (e.g., Malsch et al. 2018). Thus, the SUNDS afforded not only opening up in tool development, but in the debate on nano risk governance altogether.

In this case study, R(R)I experts (i.e., R&I consultancies) took on TA's interventionist role and primarily ensured the usability of the tool. Yet, they also fostered reflection about the SUNDS, its potential applications, and the wider discourses which it could mediate and affect. Thus, R(R)I expertise intervened both in a concrete sense, by suggesting new aspects to be included in the tool, as well as with regard to meta-perspectives, by linking the tool to wider governance contexts.

8.1.4. Summary of my case study analysis

In the last section, I have discussed in detail how opening up and closing down are constituted in each case study. To provide an overview on my findings, Table 5 summarizes them according to the three dimensions in each case study.

Table 5: Overview of findings according to the three dimensions by case studies

	Social Dimension	Epistemic Dimension	Normative Dimension	*Message*
Public Sense-Making: **Myth Formation in Neuroenhancement**	– Regarding the set-up of the cast study: selective broadening out means to involve the public in the debate – Broadening out is hoped to open up the debate eventually – Opening up the debate through a broad range of myths (introduced by hitherto marginalized actors)	– Opening up myths themselves so that they remain adjustable to social contexts – Myths as public heuristic and intentional closing down – Closing down: selectively emphasizing characteristics according to an overarching perspective	– Closing down as colonizing the future	*Involving the public can be seen as an attempt to open up debates as they introduce a broader range of interpretations. However, myths as public sense-making tend to colonize the future and close down debates early on.*
Dialogue: **CSO Engagement in Synthetic Biology**	– Broadening out the debate by organized public engagement – Compared to protests, invited engagement broadens the actor base – Gatekeepers: of opening up (reaching out) and closing down (not all stakeholders) simultaneously	– Closing down of the ontology of SB affects conceptions of risks – Opening up by bringing in novel issues – Closing down of individual positions: broadcasting instead of balance	– Opening up through different understandings of issues (weak vs. strong sustainability) – Opening up as adding perspectives and spaces for renegotiation (framing sovereignty of CSOs) – Closing down as manifested perspectives – Decision-making context as pre-framing issue at stake (closing down)	*Involving specific public actors holds potential for opening up, depending on the format and framing at stake. To ensure that different perspectives are captured, a variety of engagement formats and framings is needed to open up the debate.*

	Social Dimension	Epistemic Dimension	Normative Dimension	*Message*
Affordances: **Computational Modelling in Nano Risk Governance**	– Broadening out through new actors compared to traditional risk analysis (but overall limited) – Target groups remain closed down due to complexity of the tool	– Opening up through shifts in concepts considered by the tool – Latent opening up of future tool for new concepts	– Overall frame remains rather closed down as it adheres to quantitative risk assessment (regulatory requirement) – The role of opening up differs between understanding the tool as industrial application and scientific endeavor – Selective opening up through imagining new concepts – Opening up of wider debates through the tool	*Both scope and purpose limit the tool's affordances, although certain shifts can be observed. By introducing additional affordances, the tool may contribute to open up the societal debate on risk governance.*

8.2. Dynamics at play

To learn more about opening up and closing down in relation to public sense-making, dialogue, and affordances, I analyzed the case studies individually (section 8.1). To further reflect on the dynamics between opening up and closing down, I will now follow the three dimensions to explore my findings in the three cases. In my analysis, I distinguished between the social, epistemic, and normative dimensions; yet I am well aware that they are empirically inseparable. By foregrounding each of these dimensions individually, I hope to delve deeper into the dynamics between opening up and closing down. Following this approach, I identified three main aspects that I will explain in more detail below.

First, discussions on opening up and closing down most frequently address the social dimension, which is also best reflected by practitioners in the field. The social is expected to approximate epistemic and normative inputs, as new actors will bring new knowledge and values, too. My analysis, however, shows that this approximation does not necessary hold and that opening up and closing down in the epistemic or normative dimension do not *automatically* respond to a wider or narrower range of actors involved, although such tendencies exist.

Second, I found that the epistemic dimension is the *most variable* in terms of how it manifests. It solidified in narratives or different kinds of data, depending on where the case study is positioned along the innovation stream, and its overall normative setting. However, specific epistemic input sometimes affected the normative scope to a certain degree: considering additional analyses and approaches in appraisal or models, i.e., social aspects, succeeded in shifting the scope of the overall debate or tool to a limited extent.

Third, the *normative dimension dominated* in all of my case studies, and considerably affected both the social and epistemic dimension. This indicates that often the core of contestations is value-based and tends to prevail, irrespective of social or epistemic peculiarities of individual cases.

8.2.1. Opening up as a social task?

When foregrounding the social dimension, opening up aims at sustaining a broad range of actors consistently during the respective activity. Assuming knowledge and values to be embodied traits, this ideally results in maintaining a broad range of options for STI governance. In contrast, closing down or narrowing down refers to the exclusion of actors, and thus, knowledge and values. The social dimension therefore referred to actors and their roles in STI governance, and turned out to be crucial for opening up and closing down in all case studies. Likewise, the literature, including literature on R(R)I, identifies the social dimension as a dominant aspect in determining opening up and closing down. Based on the assumption of technocratic settings with only few actors involved, literature assumes STI governance discourses as equally closed down. Enhancing inclusion then broadens out, if not consistently opens up these discourses. Even Stirling (2008), who stated that phenomena of opening up and closing down affect participatory as well as analytical approaches, strongly emphasized the importance of including a more diverse range of actors in social appraisal and STI governance.

In general, my case studies relied on the assumption that a broad range of actors approximates a plurality of perspectives, in particular as they were concerned with including *marginalized* actor groups. Yet, who was considered marginalized differed considerably between case studies. All case studies involved actors that had not been

adequately represented in the respective discourse before and highlighted the importance of inter- or transdisciplinary collaborations by engaging either the lay public or various stakeholders. Two case studies engaged with the public directly as unorganized lay public or as organized public in the form of CSOs. The case study on computational modelling did not involve the public and only considered their stakes as modelling factors (e.g., consumer exposure models). Instead, it emphasized the importance of interdisciplinary collaborations. Thus, I found that all case studies aimed at enhancing the variety of actors involved to gain diverse input. Yet, opening up or closing down exceeds a simple broadening out of the actor base.

My case studies provided a range of insights on how opening up or closing down manifest in the social dimension. In particular, they indicated what opening up and closing down entail in context of upstream and downstream engagement. Early upstream engagement aims at opening up an STI (governance) debate altogether. If actors were to engage consistently, I found that they need engagement formats to align with requirements of wider governance, since the latter define the overall roles of actors in STI governance. In contrast, downstream engagement was mostly confronted with mechanisms of closing down: first, the demand for specific expertise to contribute to specific tasks of STI increased; second, involving new actors got more and more difficult and was often assigned to representatives of specific communities. Thus, closed down framings limited opportunities for some actors to engage in invited formats, which resulted in their consistent exclusion. This is especially problematic as the impact of individual perspectives increases considerably from early upstream to downstream engagement.

Early-upstream deliberation projects such as NERRI or SYNENERGENE conducted multi-stakeholder dialogues on specific technologies (neuroenhancement or synthetic biology, respectively). They aimed at including the (lay) public and CSOs in opinion formation and STI governance. Scholars have criticized early-upstream engagement for *lacking embeddedness* in wider sociotechnical contexts as well as lay people's everyday life, and considered such activities 'participatory experiments' rather than tangible contributions to decision-making (Bogner 2012b). Thus, some scholars observed that "science studies scholars are increasingly intervening in shaping and facilitating science-society interactions" (Chilvers 2008, 180). However, this interventionist role may entail *mismatches in assigning roles and functions* to the actors involved. These mismatches strengthen tendencies to close down engagement settings, in particular, when the functions assigned by organizers do not match actors' self-perception. For example, in one of my case studies, CSOs considered one engagement setting closed down, i.e., pre-framed, from the outset, and consequently refrained from participating. In contrast, engagement formats where the framing power remained with the actors involved, allowed for opening up the range of actors. This corresponds to findings of Ferretti and Pavone (2009), who argued that CSOs considered themselves as 'co-productive' and preferred to be involved in opinion formation from scratch, instead of taking on the assigned role of 'democratizing expertise', i.e., filling predefined knowledge gaps (Ferretti and Pavone 2009).

In downstream engagement, mechanisms of closing down become more obvious as STI increasingly manifests, just like its relevance for actors. More and more, actors base their engagement on their own stakes, which implies that their perspectives solidify and

close down. For example, in my case studies, CSOs presented their perspectives as non-negotiable and eventually enforced a closure of the debate on household products potentially using synthetic biology. Thus, the closer engagement settings move to concrete decision-making structures or procedures, the more they close down (see Chapters 6 and 7). With regard to actors, this *proximity to decision-making* structures and the deriving closing down have two main implications. First, they imply that fulfilling specific functions for governance requires expertise, which again, limits the respective arena of actors. Second, they imply that involving new actors gets increasingly difficult and is often assigned to representatives like gatekeepers to specific communities. My case studies illustrate both implications. The cases of CSO engagement and computational modelling showed the increased need for expertise, either in terms of scientific disciplines or practitioners. In particular, tailoring a computational modelling tool to a specific governance function such as risk management required aligning the tool's affordances with existing practices. As a result, it targeted specific imagined user groups rather than a broad range of actors. Consequently, it involved some stakeholder groups (e.g., policy makers or industry) more consistently in its development than others (e.g., CSOs, consumers, or citizens). Hence, the social dimension remained closed down, which considerably affected the epistemic and normative dimensions.

The second implication of closing down when closer to decision making is the challenge to engage new stakeholders. This is best illustrated by looking at how engagement was initiated in my case studies. In the context of CSO engagement, ways of initiating engagement ranged from self-empowerment and advocacy (e.g., in the case of protests) to invitations required by research funding (e.g., in cases of R(R)I-based or R(R)I-inspired multi-stakeholder dialogue). With resources of invited engagement usually being limited, 'gatekeepers' provide a helpful link to a broader actor community. Yet, if opportunities to bring in specific positions remain restricted, this strengthens tendencies of exclusion. Eventually, this may backfire when actors keep demanding a say, as I showed in the case of CSO engagement.

I did not only investigate the dynamics of opening up and closing down within the social dimension. Rather, I analyzed how the social *converges with or diverges* from the epistemic and normative dimensions. As outlined above, practitioners in the field frequently assume that a broad and continuous engagement of actors automatically corresponds to epistemic and normative diversity. This is because knowledge or values are considered embodied traits in participation and societal engagement. Social aspects entail epistemic and normative ones, and, as a result, each engagement activity consists of a unique combination of embodied knowledge and values. The respective requirements of engagement, like the level of expertise or the scope of the setting, shape this situational manifestation of discourse. In this understanding, excluding certain actors technically results in a limited knowledge base or selected normative positions. In my case studies, I found manifold examples in favor of opening up, by enriching the range of perspectives consistently through involving more actors. In the case study on public sense-making, a general lay public was empowered to contribute to the governance of neuroenhancement; in the context of dialogue, a broader range of stakeholders provided more diverse arguments; and in the case study on affordances, inter- and transdisciplinary collaborations allowed to design more comprehensive modelling approaches.

However, a simplistic equation of "the more, the merrier" is inconclusive. Enriching the actor base of STI and STI governance does not *automatically* imply an opening up on an epistemic or normative level as often assumed in literature. Rather, as Chilvers (2008) put it, "increasing the range of actors involved may provide further opportunities for reflexivity to be constrained, reduced, or subverted" (Chilvers 2008, 180). Examples where the range of perspectives does not rely on a one-on-one engagement of actors are *mediated ways* of including actor perspectives. My case studies supported, but not always favored, a direct engagement of stakeholders and the public. Sometimes, organizers referred to the argument of manageability and considered some perspectives in a mediated way, i.e., advocated by specific actors. Examples are CSOs representing the perspectives of farmers in the case study on dialogue, or consumer exposure models representing consumers in the case study of affordances. Literature has criticized such 'representative' approaches because perspectives within actor groups are usually more varied than assumed, a finding illustrated by Ahrweiler et al. (2019). Addressed as 'representatives', actors appear in a rather stereotyped way, instead of representing a range of different perspectives. For example, in the case study on dialogue, CSOs brought different perspectives to the fore, from technology-critical perspectives to organizers of events. Also, in the case study on affordances, project partners observed that the results of their mental modelling study challenged established assumptions about potential users (Malsch et al. 2017).

More broadly, some scholars have criticized *mediated ways* of engagement for the threat of excluding actors or their positions (see section 2.3). However, in practice, mediated approaches provide the advantage of minimalizing knowledge asymmetry in engagement settings and collaborations. This allows to – comparably easily – find a platform for deliberation. In the case study on affordances, the basic agreement on a perspective (i.e., risk-related and science-based) enabled the interdisciplinary collaboration in the first place. However, this framing selected aspects of discourse that manifested in the tool. Consequently, the tool aligned with a mainstreamed understanding of risks, which, yet again, affected engagement practices. In this way, the social and epistemic dimensions mutually shaped each other. Thus, while "the more the merrier" may not be the ultimate wisdom, 'mediated' ways of engagement need careful reflection with regard to opening up.

To sum up, the social dimension is central in all my case studies. It manifests differently along the innovation stream: while variable in upstream engagement, it becomes increasingly specific the closer it moves to decision-making, for example regarding required expertise for participation. I also found that including more actors does not automatically lead to an epistemic and normative diversity. Mutually defining a *common understanding* of the issue at stake turned out to be a prerequisite for broad and open discussions, rather than focusing on broadening out the actor base of engagement only. In this way, the social, epistemic and normative dimensions definitively shape each other. Moreover, my case studies showed that actors are more diverse than the stereotypical ideas that often define engagement settings. Therefore, the simplistic equation of "the more the merrier" does not necessarily hold with regard to opening up and closing down the social dimension.

8.2.2. Opening up as an epistemic task?

In my empirical work, the epistemic proved to be the *most diverse* of the three dimensions. In this context opening up indicates maintaining a plurality of epistemic aspects throughout the whole process, while closing down means their reduction. Opportunities to bring in issues and knowledge affect actors' willingness to participate in engagement activities. Thus, opening up and closing down become most effective in how a debate is pre-framed, implying that the epistemic and normative are closely intertwined. This intertwining shows in two regards: first, in defining issues and core concepts; second, in the positioning alongside the innovation stream, which considerably affects how the epistemic dimension is constituted.

First, the *definition of issues and core concepts* was crucial in all my empirical work. In the case study on public sense-making, for instance, a scientific consortium initially defined neuroenhancement as the non-therapeutic enhancement of mental capabilities. Only this rather narrow definition steered a controversial debate; other understandings, like using neuroenhancement to restore mental capabilities (i.e., medical therapy) were considered less controversial. In the context of dialogue, defining a certain practice (not) as synthetic biology affected the conceptualization of risks. If actors categorized the practice as conventional biotechnology, risks appeared as well-assessable and well-assessed by established risk assessment; if actors characterized it as synthetic biology, they called for new procedures to assess and control novel risks. Looking at affordances, computational modelling promoted traditional risk concepts, yet allowed their gradual extension. For example, the decision to move from a sole focus on risks towards sustainable manufacturing altered the knowledge bases required for analysis. Although they remained side-lined compared to the tool's main mandate, socioeconomic analyses made visible and promoted these 'new' knowledge aspects. All these examples illustrate how shifts in concepts and knowledge bases affect and open up or close down the wider debate, respectively.

Second, I confirmed that the *positioning of the case studies alongside the innovation stream* effectively impacts opening up and closing down. As outlined above (section 2.3.2, and elsewhere), I keep to the well-established metaphor of the 'innovation stream' without buying into its reductionist assumptions. I am aware that innovation is complex and non-linear (for notions of this under R(R)I see von Schomberg 2013, von Schomberg and Blok 2019), yet with regard to participation and societal engagement, and in particular the availability of reliable information, the innovation stream metaphor still serves its purpose. Indeed, I found that the context of the respective setting strongly affects the epistemic dimension. Whether a setting is located early upstream or downstream defines the kind of knowledge that is available about a technology, its robustness and reliability, and how it can be generated.

For early upstream engagement, reliable knowledge is scarce *a priori*. Early-upstream engagement is limited by a restricted availability of reliable knowledge about a technology or its consequences (see e.g., Sykes and Macnaghten 2013). Therefore, public sense-making relied on common-sense and everyday experiences. In terms of knowledge production, myths constitute a way of *public heuristics*: they suggest interpretative schemes for complex phenomena and allow lay people to acquire information and familiarize themselves with unknown phenomena. Since scientific and technical knowledge are still lacking, technology myths outrank them as a source for interpretations

in public sense-making. They provide a narrative shortcut to comprehend unfamiliar technologies without relying on analytic knowledge. As a result, they close down perspectives as they are themselves closed down structures: they *colonize the future* in a deeply ideological way (see Chapter 5). Technology myths select some traits of technologies and black box others when transferring their characteristics. Moreover, the narrative structure of myths makes them susceptible to changes in sense-making and interpretation mechanisms, rather than data or scientific knowledge. As objects of analysis, technology myths enrich and broaden out the interpretations of technologies. We found that people interpreted neuroenhancement in different ways, from daily routines (drinking coffee) to the abuse of illegal substances (taking drugs). Accordingly, people's perceptions of risks and health impacts, distributional fairness, and moral scruples differed considerably, depending on whether neuroenhancement counted as harmless stimulant or sketchy practice. Thus, this case study clearly illustrates the convergence of the epistemic and normative dimension early upstream, up to the point where the normative overshadows the epistemic, and narratives, not analytical knowledge, become the first sources of information.

Further downstream, reliable analytical knowledge becomes more and more available, gradually decreasing the overt power of the narrative. Participants in dialogues and collaborations mobilized perspectives based on analytical knowledge; hence, the basis for argumentation shifted. Consequently, opening up signified consistently considering a broad knowledge base, either through the self-motivation of actors or through mapping out epistemic aspects. For example, in the case study on dialogue, CSOs succeeded in raising the issue of global fairness consistently, i.e., opened up the debate altogether. In contrast, the case study on affordances indicated a tendency towards epistemic closing down. Here, the underlying positivistic position of expert discourses on risks emphasized established scientific analyses. Yet, the conceptual shifts in tool development revealed that here normative and epistemic aspects are also closely entangled: while some of these shifts aimed at better approximate real-life conditions, others allowed for integrating precaution with innovation principles.

Both the case study on dialogue and on affordances indicated that analytical knowledge did not completely displace narratives. Rather, narratives persisted in a more obscured way. They defined the overall frame of how to consider analytical knowledge and by so doing closed down the respective setting, while knowledge could diversify and be adapted. I found that former technology controversies served as a reservoir for narratives (i.e., lines of argumentation) for current debates. Most prominently, this featured in the case study on dialogue, where some actors considered synthetic biology as 'GMO 2.0' with unknowable consequences, while others saw it as a harmless and well-assessed practice; over time, both narratives became peppered with analytical knowledge. Likewise, in the case of affordances, a shared understanding of risk analysis anchored individual approaches. The overall scope of the tool – sustainable manufacturing – defined its affordances and marginalized more ambiguous aspects not fitting the overall narrative (like ethics for example). Consequently, affordances only mirror sufficiently closed perspectives (e.g., how to operationalize sustainability). Thus, all my case studies underlined the importance of narrative structures for ordering analytical knowledge. Yet, the relation between narrative structures and analytical knowledge shifts considerably alongside the innovation stream. Constituting the main source of knowledge early

upstream, narratives continue to affect issues downstream, complemented by available scientific and technical details. Consequently, the epistemic dimension is constituted by different kinds of knowledge and knowledge production, be it analytic or participatory knowledge, or narratives like myths. This makes it the most diverse dimension of my analysis. In addition, I showed how closely entangled epistemic and normative aspects are, with epistemic aspects enriching perspectives in line with the respective normative frame.

To sum up, opening up or closing down play out differently according to different knowledge bases, from narratives to analytical data. For opening up, being able to *define or re-define issues and practices* is fundamental. This indicates the importance of the normative dimension: as framing defines which knowledge to consider, the normative often overpower epistemic aspects. Nonetheless, with a common basis for dialogue, framings can shift. This allows to exchange knowledge and perspectives, and to eventually alter, and open up established perspectives and underlying narratives.

8.2.3. Opening up as a normative task?

The normative dimension of opening up implies including a broad range of values in a consistent way. Most notably, I found that established political or societal contexts pre-frame new STI activities, and that normative attitudes are persistent, contingent on prior assumptions and decision-making. These conditions pre-frame, i.e., close down, how issues at stake evolve. Yet, at the same time, they leave space for opening up, i.e., for integrating hitherto marginalized issues in debates – at least to a limited extent. In addition, I found that the normative dimension defines how dialogue should be conducted.

Overall, all my case studies indicated that narratives and perspectives only *change slowly* over time and persist beyond individual engagement settings. I found that prior assumptions and underlying values continued to prevail in current controversies and perspectives, only changing in detail. Conveyed imaginations of STI closed down opportunities to introduce new perspectives pre-maturely. These imaginations spanned from individual framings of a debate to broader narratives that colonized ideas of the future, i.e., ideas of commercialization or social progress, accumulating into a meta-perspective of risk and control.

Framings closed down the debate selectively, oriented debates and defined appropriate knowledge bases and approaches of knowledge production. This could be observed in each case study. In the context of public sense-making, myths as narrative shortcuts closed down perceptions on neuroenhancement through referencing established, normatively charged practices (i.e., drinking coffee or taking drugs). With regard to dialogue and affordances, closing down related to the problematization of technologies. The focus on risks imposed a specific perspective on how to handle emerging technologies and marginalized alternative framings. In relation to dialogue, diverging ideas on sustainability colonized different strands of arguments by aligning current conflicts and perspectives with prior contestations on gene-editing and biotechnologies. Here, controversies about synthetic biology constituted a continuous effort to open up normative aspects by calling for a fundamental rethinking of established structures, i.e., to overcome a technical framing of sustainability. To mobilize their clientele, critical CSOs linked synthetic biology to broader issues like biodiversity, turning it into one aspect among many relevant for sustainable development. Looking at affordances, a risk-based understanding of governance called for a science-based computational tool. Yet, shifts in affordances

challenged the conventional framing of risk governance: the notion of 'sustainable manufacturing' allowed molding the issue of sustainability into the tool's scope and to consider additional aspects like socioeconomic analyses. Thus, normative ideas of STI were conveyed into epistemic issues, opening up the debate. At the same time, persisting practices in and imaginations of risk governance narrowed and closed down the scope of analysis: policies and assessments kept reinvigorating conventional ideas and knowledge paradigms of risk governance. As a result, assessment frameworks and computational modelling tools afforded a quantitative paradigm in line with regulation. I therefore found that closing down in the normative dimension allowed for short-cuts in sense-making and for linking my case studies to wider established practices and discourses. Yet, in turn, the wider political and social conditions closed down the individual case studies.

Opening up and closing down with regard to the normative dimension also relates to *how engagement is conducted*. It affects the very design of dialogue. Literature finds that R(R)I understands engagement as calm, rational, and well-balanced, where actors extend beyond their own interests to acknowledge the interests of others (e.g., Bauer, Bogner, and Fuchs 2021). In my case studies, invited forms of downstream engagement followed this understanding by promoting a mediated exchange of perspectives, i.e., advocates fostered specific perspectives in inter- and transdisciplinary settings. However, this understanding bore the risk of marginalizing other forms of engagement, such as the call of critical CSOs to rethink established structures, i.e., the current innovation paradigm. CSO perspectives hardly opened up themselves; thus, other actors often perceived them as a challenge to rational dialogue. Depending on the engagement setting, such an opposition entailed different consequences. In early upstream engagement, contradicting perspectives often co-existed. This does not align with R(R)I's ideals of dialogue in a strict sense, yet it broadened the overall landscape of perspectives and provided a potential for eventually opening up the discourse altogether. In addition, expanding their activity repertoire beyond balanced dialogue allowed CSOs to reach their objectives without compromising. In the specific case of synthetic biology, building up pressure led to an alternative closure of the debate at hand.

In general, I found that the normative dominated over the social and epistemic dimensions. This was indicated by the *persistence of narratives*, as well as the overall commitment of my case studies to foster *inclusive settings*. These normative commitments frame epistemic aspects as they define which issues or forms of knowledge to consider. For example, in the context of public sense-making, the decision to not only include experts, but lay people in STI governance changed the form of knowledge under consideration. Also, normative aspects predominated: regarding dialogue, they affected whether synthetic biology counted as a valid means for sustainable development or not; in the case of affordances, they defined whether the quantitative ideal of regulation outweighed everyday qualitative experiences.

My analysis showed that the normative dimension shapes the conditions for public sense-making, dialogue or affordances, including the question which actors should be involved. The normative defines how agency is enabled or constrained in specific settings while it is *hardly ever closed down definitively*. For example, new epistemic aspects may affect the overall framing of a setting over time if it is flexible enough. Remember how in the case studies on dialogue and affordances, new epistemic aspects like social issues and socioeconomic analyses shifted the normative question how to consider consequences of

technologies. Yet, such indicators remained side-lined compared to more established indicators of risks, especially in the case on affordances. Nonetheless, when actors firmly advocated specific perspectives, they were able to extend the overall landscape of perspectives. Also, the normative commitment for inclusion cumulated at least in broadening out of the respective actor bases, and, to a certain extent, of issues or landscapes of perspectives. This potentially opens up STI and STI governance altogether and indicates the negotiability of the normative dimension. However, closing down is also mostly defined by normative aspects. After all, some boundaries and a (temporary) closure of debate are necessary to move from deliberation towards action. How to achieve this in a transparent and just way, however, is up for debate.

8.2.4. Summary of the cross-case analysis of opening up and closing down

Table 6 sums up the findings of the cross-case analysis of the three dimensions with regard to opening up and closing down.

Table 6: Overview of findings on opening up and closing down

	Opening Up	Closing Down
Social Dimension	*Addresses actors and roles*	
	Prevailing assumption: including a broad range of actors equals more diverse input (to be proven)	
	– Upstream engagement: open, but without link to concrete decision-making – Potential mismatch between the imagined roles of actors and governance structures	– Downstream: established structures require expertise and hamper including new actors – Indirect (mediated) involvement as (mediated) closing down?
Epistemic Dimension	*Addresses issues and knowledge bases*	
	Depends on innovation stream: most variable dimension	
	Closely entangled with the normative dimension	
	– Broadening out as adding issues – Opening up as (re-)defining issues – Opening up through integrating new analyses	– Upstream: public-sense-making as closed-down structures – Downstream: frame usually set (e.g., scientific deliberation) & narratives remain
Normative Dimension	*Addresses values and normative orientation*	
	– Broadening out as considering additional values – Opening up as (re-)defining issues, including linking to more accessible debates	– Framing as way to close down settings and discussions – Dialogue as strong framing device (rationality) *per se* – Closing down of perspectives as strategic advantage (higher impact through non-negotiability) – Closing down only changes slowly – Never closed down definitively?

8.3. Lessons about public sense-making, dialogue and affordances

After reviewing my case studies individually (section 8.1) and the three dimensions and their roles in opening up and closing down across cases (section 8.2), I am now in a position to reflect on the generic conceptual lessons about opening up and closing down. Arguably, the best way to do this is to follow the very mechanisms – public sense-making, dialogue and affordances – that my case studies explored. What did I find about these mechanisms and what does this hold for the phenomena of opening up and closing down?

As a first step to look at these questions, I point to the specific characteristics of each mechanism. Public sense-making implies that lay people are capable of making sense of previously unknown technologies (i.e., neuroenhancement) in their own way and that these mechanisms differ from those of professionals (i.e., experts). It focuses on how lay people familiarize themselves with new matters when information is still scarce (i.e., emerging myths). Dialogue is a relational concept between different individual or collective actors that emphasizes communication, mutual understanding, and comprehension. It is a multi-stakeholder interaction that can be moderated, as imagined under R(R)I, or emerge out of self-motivation, e.g., as a result of protests. Affordances are materiality-bound and emphasize the (physical or virtual) conditions of activities that they suggest. Affordances invite users to use a technology or artifact in a specific way (or behave in a specific manner), while allowing for a certain freedom of choice for users. In the following, I zoom in on these different mechanisms and their relation to opening up and closing down.

First, I consider *public sense-making* to see what it implies for opening up and closing down. Technology myths as a specificity of public sense-making reduce the interpretative flexibility of the technology at stake. They do so by emphasizing specific features, closing down the respective interpretation at an individual level. Yet, when looking at public sense-making as a collective activity, it allows for opening up the range of positions towards a specific technology. Thus, no matter how closed individual interpretations may be, public sense-making is open to explore different interpretations of a technology simultaneously. This is strengthened by the scarcity of reliable information upstream, which results in a marginalization of technological specificities in public sense-making and opens up the issue under investigation to imagination. As a result, people can easily share their understandings, opening up the range of interpretations.

Second, *dialogue* places emphasis on the relation between different actors. By so doing, it allows to explore specificities of collective learning and strengthens learning at eye-level. Ideally, this could overcome information asymmetries, and participants may open up each other's perspectives by openly discussing them and challenging potential blind spots together. This ideal very much resembles Habermas' "rational communication" (for details see section 3.3.2). Yet, to consistently open up the debate, the lessons of collective learning need to be preserved and conveyed along the innovation stream. This poses a tremendous challenge in practice, especially when considering the variety of actors who contribute to innovation. In addition to the exchange of information, dialogue may serve other, foremost social purposes. Dialogues allow for networking, i.e., for establishing new or strengthening existing relations to other actors. These relations may, again, contribute to stabilizing endeavors of conducting dialogue, or, if strong enough, allow for concrete collaborations on specific topics. Therefore, they may open up, extend, and stabilize possibilities of interaction between actors. However, to do so, dialogue needs some

kind of established common ground or a platform for communication: this may be an understanding of the issue at stake (say, a common definition) or an understanding of how to facilitate integrating different knowledge bases and long-term perspectives.

Third, the material qualities of *affordances* mediate a specific status quo while allowing the user to make sense of them in their own way. Affordances are characterized by durability and immutability due to their material aspects, while keeping a flexibility in interpretation and in their use. Affordances allow looking at solidified features of discourse and to explore boundaries of discourse and dialogue. In this way, affordances constitute 'boundary objects' in a physical or virtual sense: they may fuel discussions on technical lock-ins or broader questions of governance, which, again, may affect the artifacts themselves. Thus, they emphasize durable features of discourse and tend to make it more rigid; as a result, they strengthen the importance of established features, and imply a certain tendency to close down debates.

Looking at the mechanisms addressed by my case studies emphasizes the different qualities of each. Most notably, public sense-making and dialogue are speech-based mechanisms, while affordances explicitly consider materiality, or virtuality for that matter. This distinction alone suggests different relations to opening up and closing down. *Materiality* brings specific qualities like durability and immutability to the table, which affect sociomaterial practices (also see section 3.3.2). In the context of public sense-making and dialogue, these traits hold new implications for opening up and closing down. For example, when familiarizing oneself with new content, affordances will provide a template for doing so, i.e., filter options according to established characteristics and close down the options considered from the outset. Dialogue, like public sense-making, is speech-based and, in principle, *flexible and negotiable*. Yet, when acquiring traits of affordances, it becomes more rigid in its implementation. In a very loose sense, approaches of invited engagement may be considered a modest (and still quite flexible) form of affordances, as they close down dialogue to a certain extent. Voß and Amelung (2016) have argued in a similar manner when they wrote about a "technology of participation" (Voß and Amelung 2016, 763). Although affordances show the strongest tendencies in this respect, all three mechanisms can be understood as ways to close down discourse. They all manifest (social) negotiations, be it as dialogue, as different interpretations in public sense-making, or as (physical or virtual) artefacts. Foregrounding these manifestations allows to highlight their specificities and to give way to negotiate them anew, hence for opening up the respective debates.

To conclude, my work emphasizes that opening up and closing down entails more mechanisms to configure STI (governance) than inviting stakeholders for dialogue. My core finding is that processes of opening up and closing down occur through different mechanisms, including public sense-making and collective narratives, dialogue and discursive exchange, and affordances of tools and instruments. Thus, phenomena of opening up and closing down are omnipresent and take various forms in how they manifest, yet they are shaped by their respective mechanisms.

As a summary, Table 7 provides an overview on the definitions of mechanisms and how they contribute to opening up and closing down.

Table 7: Mechanisms and their contributions to opening up and closing down

Public sense-making *Familiarizing oneself with unknown things under information scarcity*	– Public sense-making allows to explore different interpretations of technology as technological specificities are marginalized – Individually, public sense-making closes down the interpretative flexibility of the meaning of technologies by emphasizing specific features
Dialogue *Moderated or self-motivated multi-stakeholder interaction*	– Dialogue puts emphasis on collective learning at eye-level – Dialogue allows to even out information asymmetry between actors, opening up one's perspective if conveyed in the right "mode" – Additional functions of dialogue allow for networking and building/strengthening long-term co-operations (in principle) – Dialogue needs a specific kind of platform to find common understanding and to collaborate
Affordances *Suggested ways in which a technology or artifact invites to be used*	– Affordances point to materially manifested, i.e., durable, features of discourse and turn into physical/virtual boundary objects – Affordances make the implementation of dialogue and public sense-making more rigid and closed down; additional functions of dialogue (networking) may become deemphasized

9. Concluding remarks and lessons learned

In this thesis, I investigated the phenomena of opening up and closing down. They are crucial for understanding how agency in STI governance is enabled or constrained, and how its conditions are shaped, respectively. I used opening up and closing down to look at participation and societal engagement, which constitute both a condition for and a consequence of opening up and closing down at the same time. Moreover, I followed opening up and closing down in different manifestations of participation and societal engagement, as sense-making, dialogue or affordances.

Generally speaking, conveying lessons learned between case study contexts as diverse as mine is challenging. Even more so because my conceptual approach shows that the tendencies to open up or close down are frequently fragmented and complex. Nonetheless, in this chapter, I try to provide some overarching concluding remarks and lessons learned. With my thesis, I aspired to address calls of social scientists for investigating the "environment of participation" (Chilvers and Kearnes 2016) and to move towards a "far-reaching form of dialogue, deeply embedded in governance" (Sykes and Macnaghten 2013, 101).

Through my diverse case studies, I have gained a *more systematic insight* into how different forms of participation and societal engagement allow for *opening up and closing down in STI governance*. To do so, I explored the following questions:

- What does it mean to open up or close down?
- How do opening up and closing down manifest in different instances of STI?
- How do opening up and closing down relate to each other?
- What are implications of the dynamics of opening up and closing down for participation and societal engagement, and STI governance more broadly?

I enriched the understanding of how agency is enabled or constrained by disentangling the social, epistemic and normative dimensions that constitute tendencies of opening up and closing down.

To do so, I selected three case studies at *different 'stages'* of innovation (see my critical reflection on using the metaphor of the innovation stream in 2.3.2 and elsewhere). Each addressed a different emerging technology (neuroenhancement, synthetic biology and nanomaterials). Moreover, each case study represented a specific mechanism that enacted opening up and closing down: public sense-making manifesting in technology myths (Chapter 5); dialogue in the light of prevailing interests of actors (Chapter 6); and affordances of computational models conceptualizing risk governance (Chapter 7). Thus, I expanded the scope of participation and societal engagement beyond a sole focus on actor deliberation. Accordingly, my analysis also focused on narratives and socio-material manifestations of discourse (i.e., computational modelling) as objects of study. This required additional concepts (i.e., myths, affordances) to capture the superordinate concept of agency. Hence, in my case studies, I mobilized additional concepts, such as myth formation, roles, frames and formats, and affordances to explore how agency is generated, organized, and maintained.

I used the *social, epistemic and normative dimensions* to thoroughly investigate the dynamics between opening up and closing down, in each case study as well as in a cross-case analysis. By so doing, I found that the three dimensions converge to different extents. The social dimension, i.e., the inclusion of actors, is often thought to be crucial for

opening up or closing down in STI governance, including R(R)I (see van Mierlo, Beers, and Hoes 2020, Owen et al. 2013, Stilgoe, Owen, and Macnaghten 2013, Owen, Macnaghten, and Stilgoe 2012). Thus, it is omnipresent in my thesis. Yet, I found that other dimensions typically affect the tendency to open up or close down even more. Also, the conditions of opening up and closing down influence the three dimensions to different extents. The epistemic dimension for example is highly contingent on the case study's position alongside the innovation stream, which has impacts on the manifestation of issues and the availability of analytical knowledge. I confirmed that the epistemic and normative dimensions are often combined as framing to orient debates and provide information (cf. Stirling 2008). By disentangling the social, epistemic and normative dimensions I fine-tuned this finding and discovered that the normative dimension defines both actors and knowledge through framing. In addition, the normative cannot be closed down completely, i.e., remains negotiable at least in principle. This implies that shifts in the epistemic or the social dimension can, again, affect the overall framing.

In short, my core research interest was how opening up and closing down are constituted in different STI governance settings of emerging technologies. This chapter provides concluding remarks about opening up and closing down, in theory and practice. Foremost, it addresses the general dynamics of opening up and closing down in STI governance (section 9.1). In addition, I also share insights on discourse and dialogue to better anchor my findings on participation and societal engagement on a practical level (section 9.2).

9.1. Opening up and closing down as dynamic interrelations

To define the dynamic interrelation of opening up and closing down, two aspects turned out to be crucial: first, that the proximity in decision-making defines the scope of agency; and second, that normative contestations shape how agency is being enabled or constrained.

9.1.1. Proximity to decision-making affects the scope of agency

The literature on public participation in STI for large parts considers STI processes as (mostly) technocratic situations, for which opening up turned into a goal in itself (Chilvers 2008). Consequently, Stirling (2008) understands opening up and closing down as subsequent steps in STI governance – in a first step, social appraisal of technologies is opened up, before the debate is closed down transparently to prepare technology commitment. In contrast, conceptualizing opening up and closing down as empirical rather than normative phenomena suggests that they are, in fact, variable and dynamically intertwined (cf. Urueña, Rodríguez, and Ibarra 2021, 6). Here, they are not considered isolated phenomena or subsequent steps of STI governance, but as contingent on the conditions of their emergence. This thesis confirmed that these conditions vary considerably between situations of STI governance; accordingly, opening up and closing down do too.

In the literature on responsible innovation, R(R)I refers to processes as well as products of STI (von Schomberg 2013, Owen et al. 2013). However, some authors claimed that R(R)I frequently *prioritizes the process perspective* over concrete outcomes (van Mierlo, Beers, and Hoes 2020, 365). My case studies showed that a prioritization of processes or products does not just reflect a preference of practitioners, but rather depends on the position of the participatory intervention in innovation. The further upstream the

situation under investigation, and thus, the more distant from pressures to close down, the more it emphasized the procedural level and dialogue. Consequently, novel aspects were included rather easily, and all three dimensions tended to open up. Yet, mechanisms of closing down became effective early upstream too, above all as a way to provide consistent narrative structures. For example, in the case study on public sense-making (Chapter 5), closing down narrative structures reduced the complexity of the issue at stake and allowed for transferring (public) knowledge between technologies. This reduction constituted a precondition for exchanging arguments to eventually create something new – despite all implied ambivalences in relation to the technology. Moreover, these closed down framings defined lines of argumentation and analytical frameworks beyond individual case studies that developed incrementally rather than radically. As a result, the range of future activities is closed down and pre-structured by past and current developments, i.e., narrative structures may become performative for downstream engagement as well.

Further downstream, in more concrete decision-making contexts, dialogues had the role of generating or providing information in addition to established positions. This situation may best approximate Stirling's original idea of opening up technology appraisal. Procedural aspects of dialogue were crucial for avoiding marginalizing knowledge bases and values, as problematized by Brian Wynne (Wynne 2001, 2003, 2005, 2007, cf. Sulmowski 2017). Organizers, like policy makers and engagement practitioners, were concerned with the design of procedures to legitimately inform decision-making. Ideally, their motivation for participation and societal engagement is based on a normative or substantial, rather than an instrumental rationale (Fiorino 1990, Stirling 2008). Engagement practitioners in particular emphasized the design of the process and, thus, deliberation, rather than concrete results, much in line with Habermas' understanding of dialogue (cf. Habermas 1992). Policy makers, however, may care about outcomes as well as processes as they need to present successful results in alignment with democratic will.

Concrete decision-making in STI governance or in contexts of responsible innovation, constitute an accumulation point of technology debates. Here, actors *prioritize outcomes* over processes, and acknowledge the necessity to close down debates. The tangibility of engagement outcomes was crucial for achieving an alternative closure of a debate (see Chapter 6). Also, technical manifestations of discourse emphasized concrete products, while the importance of procedural aspects declined (see Chapter 7). In both examples, participation and societal engagement were conducted as a contribution to a specific outcome. Here, closing down supports decision-making in STI and STI governance. To do so, the framing of the issue at stake is crucial, as framing constitutes a call to action (Beland Lindahl et al. 2016). Particularly the case study on affordances demonstrated clearly how a common framing of the aspired tool supported efficient communication and collaboration. Literature cements this finding by stating that, in turn, joining all different stakeholders and their interests without finding a common framing tends to decrease coherence of ventures, as well as organizations (cf. Hadley Kershaw 2018, Prainsack and Leonelli 2018). Yet, a common framing also perpetuated the implied power balances between actors directly or indirectly involved in the process (cf. Burgess 2014). In conclusion, this strengthens calls of responsible innovation literature to consider but also thoroughly reflect processes of closing down in STI (van Mierlo, Beers, and Hoes 2020, Tempels and van den Belt 2016).

My case studies showed that even if participation in STI is conducted as means to an end, as a way to support a particular outcome, actors could participate in STI in manifold ways: from contributing to technical solutions, to addressing remaining problems, and to communicating needs that indicate potential market opportunities. Due to the emphasis on products, R&D and innovation in the private sector highlight the importance of a substantial rationale for participation and societal engagement. Yet, although R(R)I strengthened the requirements for participation and societal engagement, involving hitherto marginalized actors remains an add-on in innovation processes. This implies that downstream, opening up only occurs in a fragmented manner.

With regard to the question how participation in STI may enable or constrain agency, several lessons stand out. First, the potential to enable agency of stakeholders depends on the *proximity of the intervention to decision-making*. The more concrete, i.e., closed down, STI or STI governance processes are from the outset, the more limited the range of potential framings that are deemed valid. Moreover, the requirements to participate become more specific (e.g., regarding expertise). This imposes a specialization and fragmentation on the discourse altogether, where each framing mobilizes a different actor constellation. To identify overarching tendencies regarding enabling or constraining agency, it thus is important to look at "ecologies of participation" in the context of participation and societal engagement (cf. Chilvers and Kearnes 2016). Such a systematic perspective shifts attention from individual participation and societal engagement settings and their conditions towards the totality of engagement practices on a specific topic. It emphasizes how participation and societal engagement are embedded in and shape wider societal conditions and therefore allows to identify overarching trends in the relations between science, public and policy.

Second, given that the *impact* of contributions of participation and societal engagement increases tremendously downstream, closing down in STI governance becomes even more problematic, even if counter-measures are attempted (e.g., inviting gatekeepers to specific communities). In addition, actors will have a more articulate view on how they are affected in a downstream situation; accordingly, their partial interest will define how they engage. This challenges a balanced dialogue as imagined by R(R)I (Bauer, Bogner, and Fuchs 2021). Indeed, my findings showed that when actors perceived their stakes as permanently excluded from public debates, STI, or STI governance procedures, rising stakes tended to resurge violently.

9.1.2. Normative conflicts cannot be resolved

By tracing the effects of opening up and closing down in the three dimensions, social, epistemic, and normative, I showed that they are not affected in the same way. Accordingly, opening up and closing down are unlikely to take place in all dimensions at once to the same extent (section 8.2). They remain *fragmented and incomplete*, and enable or constrain agencies in different ways. For example, shifts in the epistemic dimension can influence the normative to a limited extent, as I showed in my case study on affordances in computational modelling. In contrast, shifting the scope of the normative dimension had immediate and far-reaching effects on the social and epistemic dimensions. This indicates the *dominance of the normative dimension* above the other two. My finding resonates with what Sulmowski (2017) stated in reference to Longino (2013): values take on a cognition and interpretation function in research processes (Sulmowski 2017, 121).

Thus, they need to be explicated as they function as resources to support a separation between relevant and irrelevant or trivial information (Sulmowski 2017, 124).

My findings also underscore that framing, as a value-laden process, consists of epistemic and normative elements and orients further activities (Stirling 2008, Sulmowski 2017, for risk assessment see Hartley and Kokotovich 2018, Renn 2015). Stirling considered framing as crucial for opening up. Likewise, my work showed that rather than the social, the normative and epistemic dimensions defined the extent of openness of debates. In the case of technology debates, emerging frames are, again, pre-framed by long-lasting and painstaking controversies about similar technologies. In particular, the normative dimension is crucial for opening up and closing down the other two. Hypothetically speaking, if the normative dimension was closed down completely, no range of actors nor variety of issues or forms of knowledge could succeed in opening it up, but instead contribute to stabilizing the respective normative position.

However, earlier studies stress that the normative dimension *can never be closed down completely*. As Bogner (2012a) points out, normative contestations do not have a definite resolution, because there is simply no right or wrong answer to ethical questions. In contrast, 'knowledge conflicts' center around epistemic questions and can, in principle, be solved as soon as experts have agreed on what knowledge counts in the respective case and for answering the respective question. Accordingly, Bogner (2012a) characterizes these conflicts as temporary states of contestation to be overcome on the long and windy road to better knowledge. Conflicts about value questions lack such a final solution and shared normative commitments always rely on compromises between actors; hence, potential controversies can flare up easily (Bogner 2012a). Regardless, normative questions are often regarded as finally settled in individual settings while they remain pending in other political and social arenas: thus, 'value conflicts', while treated as resolved in one setting, may be transferred easily to another. For example, the case study on affordances (implicitly) deferred ethical questions to a broader regulatory discourse instead of addressing them via computational modelling. For many situations, such a transfer may appear as a valid strategy. However, it is not always a long-term solution: if excluded consistently, normative aspects tend to open up settings or debates virulently, as I showed in the case study dialogue. This indicates that while a distinction between facts and values may be constitutive for modern societies, it always implies a closing down function (Sulmowski 2017, cf. Latour 2008).

Considering normative conflicts as unresolvable has far-reaching implications for how opening up and closing down are conceptualized. For one thing, it renders a definite closure of debates impossible. Accordingly, opening up and closing down constitute *temporary* states rather than final outcomes of STI and STI governance processes. However, Andy Stirling considered a complete closure as unnecessary for decision-making and even as undesirable, as it would imply a great potential for missing innovation opportunities (cf. Stirling 2008). In summary, opening up and closing down constitute vectors rather than destinations: they are not zero-sum-states. And, most importantly, they allow for the world to remain open.

9.2. Dialogue, discourse, and opening up and closing down participation and societal engagement

Next to overall conclusions on the dynamic of opening up and closing down (section 9.1), my thesis provides practical insights on participation and societal engagement. Yet, before addressing some core issues on a practical level, I circle back to the theoretical concepts of dialogue and discourse and their implications (see section 3.3.2) to position my empirical findings.

Questions about agency in the dynamics of opening up and closing down, are inherently linked to issues of dialogue and discourse. How opening up and closing down relate to each other (please refer to the comparison of my case studies in Chapter 8), *defines conditions and requirements* of discourse and dialogue. Overall, opening up represents empowerment: entering into dialogue allows for developing new perspectives and STI pathways; yet, power constellations close down and restrict engagement – of some actors more than of others (cf. Sulmowski 2017, Stirling 2008). This addresses tensions between dialogue and discourse by Habermas and Foucault (see section 3.3.2)

As any other practice, participation and societal engagement are shaped by and perpetuate imaginaries of their ideal practice. In invited engagement as favored under R(R)I, Habermas' ideal of 'rational communication' prevails as R(R)I emphasizes a legitimate procedure over a particular normative stance and promotes a specific way of collaboration between actors (Lozano and Monsonís-Payá 2020, Bauer, Bogner, and Fuchs 2021). Early upstream engagement tends to build on this understanding of dialogue as my case studies showed: dialogue relies on ideals of actors' willingness to listen to each other, to adjust one's perspective, and to find common ground in contestations. It assumes actor positions as negotiable and actors as able – and willing – to raise arguments in a certain way. Under R(R)I, actors should look beyond their own arguments and balance them against the arguments of others (Bauer, Bogner, and Fuchs 2021). This requires that actors prioritize a common ground over particular interests and to adopt their behavior accordingly. For R(R)I, dialogue constitutes a productive endeavor that allows for something novel to emerge, from a common understanding of a problem to a solution to it.

R(R)I's preference of 'rational' dialogue and its deriving underlying consensus-orientation poses a challenge for including actors or perspectives, due to its tendency to conceal normative positions that underlie epistemic aspects. Chilvers (2008) demystified rational dialogue when he argued that *"an overemphasis on equality and fairness within these frameworks [i.e., consensual theories and methods, author's note] can hide intractable epistemic/ethical differences and hegemonic power relations. The 'myth of the best argument' (Pellizzoni 2001) is particularly exposed under conditions of radical uncertainty, as manifest through cognitive/ axiological incommensurability"* (Chilvers 2008, 179). In my case studies, this showed when actors unsuccessfully called for reframing, and refused to participate in pre-framed dialogues. This indicates the overall challenge of Habermas' rational dialogue: his ideal of renouncing power in deliberation settings is hardly ever met.

Indeed, the power constellations in which dialogue is embedded often remain unaddressed. Consequently, dialogue constantly bears the risk of reproducing power differences while keeping 'unpleasant voices' at bay. Moreover, the route of dialogue has been criticized for obscuring mismatches in framing by delegitimizing 'emotional' perspectives, such as fierce oppositions (see e.g., Delgado, Kjølberg, and Wickson 2011).

Marginalizing such perspectives is all the more problematic as value conflicts do not have a definite resolution, as I discussed above: obscuring unresolved normative issues by bringing forth epistemic ones may give rise to long-lasting and unconstructive negotiations.

Stirling's idea of dialogue in the context of opening up and closing down follows Habermas regarding the (ideal) form of deliberation, yet, differs to Habermas and Foucault with regard to how he conceptualizes power: for Stirling, power is actor-related (Stirling 2008, 274). Instead, both Habermas and Foucault both understand power as going beyond personal interaction. In particular Foucault emphasizes the *conditions of dialogue* by referring to wider discourse; for him, discourse *is* power (Foucault 1970/1981).

By conceptualizing opening up and closing down as enabling and constraining agency, I, too, looked beyond individual manifestations of discourse (including dialogue) and focused on the *conditions* of agency. Accordingly, my thesis emphasizes structural rather than action-related notions of power in social engagement and dialogue. By so doing, it complements and deepens understandings of agency. For instance, an action-centered perspective on CSO engagement led some actors to perceive CSOs' critical stance on synthetic biology as "hampering dialogue". From a more structure-oriented angle, however, the firm commitment of CSOs potentially roots in wider power imbalances: if only few – and comparably powerless – actors support a specific perspective, every advocate counts to prevent its demise. To emphasize such power constellations, I concur with Jason Chilvers, who proposes a "contextually sensitive account of deliberation", highlighting cooperation between actors without losing their individual perspectives, instead of pushing for a consensual agreement (Chilvers 2008, 179).

In my case studies, deconstructing power constellations was particularly useful when established discourses hampered integrating new empirical or normative positions, or prior conflicts dominated the current debate. Here, the slow changes in discourse mirror the sluggish shifts in power constellations. Stirling casually summarizes this when he states that closing down assists "incumbent policy-making actors […] by providing a means to (weak or strong) justification" (Stirling 2008, 278). In this regard, I argue that moving from an actor-centered towards a structural perspective on agency and power allows for a more thorough analysis of opening up and closing down and, potentially, for shifting practices in STI governance towards responsible innovation more easily.

Of course, this short review of dialogue, discourse, and power in relation to my thesis is by no means exhaustive. Yet, it highlights the importance to explore discourse and dialogue in-depths to better understand the phenomena of opening up and closing down – in particular in the light of R(R)I. STS scholars have only recently called for investigating practices of openness more closely in relation to science (policy) in R(R)I, in particular in context of phenomena like fake news and political disinformation of actors (Nerlich, Hartley, et al. 2018).

For my thesis, circling back to concepts of discourse, dialogue, and power anchors my findings on a practical level. While this was not the main task of my thesis, I would nevertheless like to end with a few observations that may be helpful for people active in the field of participation and societal engagement. So, to complete the circle of my thesis, I draw conclusions for practice on a few issues I introduced earlier: purpose and scope, timing and organizational form, actor roles, and framing (see section 2.3).

9.2.1. Purpose and scope: proximity to decision-making

Purpose and scope were central aspects in my thesis as participation and societal engagement aim at fulfilling specific governance needs. They vary accordingly, foremost dependent on their *proximity to decision-making.* In my case studies, for example, participation and societal engagement aimed at generating publicly acceptable governance options early upstream challenged governance settings to come to terms with critical voices and manifested understandings of risk governance in a computational tool. My case studies have shown how the epistemic dimension brings forth hopes and concerns about emerging technologies, expresses particular interests and various aspects of the matter at hand, or mobilizes different knowledge bases. The normative dimension shifts alongside the innovation stream and may appear less explicitly downstream, since actors tend to consider normative aspects as 'already resolved' by then. Yet, both the epistemic and the normative dimension enrich and improve decision-making from a bottom-up perspective, even if introduced via invited engagement. My studies also highlight the dangers of matching participation and societal engagement to existing decision-making agendas from the outset, inducing top-down thinking. Issues may be framed in techno-centric ways, asserting strategic interests, or steering research in a specific direction from the beginning.

Overall, reflecting on the purpose and scope early on supports the implementation of opening up participation and societal engagement. At the same time, such a reflection raises awareness regarding potential challenges, like (involuntarily) solidifying technocratic, instrumental perspectives or unexpectedly reigniting conflicts. In practice, the proximity to decision-making defines the purpose and scope too. While opening up is comparably easy in situations early upstream, downstream situations usually offer limited opportunities to reframe the purpose and scope. This does not imply that one should stay far from decision-making; instead, it is pertinent to acknowledge in what way actors can contribute here. Clearly communicating the purpose, scope, and proximity of participation and societal engagement to decision-making is crucial, in particular in invited engagement, including R(R)I, to disclose the potential flexibility in scope without compromising the transparency and legitimacy of the process.

9.2.2. Timing and organizational form: the earlier the easier?

Timing is central to participation and societal engagement because it directly affected issues, activities, constructed public interests, and the perceived urgency to act. *Timing influenced the positioning of engagement practices* alongside the innovation stream, their proximity to decision-making, and how to address ethical questions.

My case studies showed how the flexibility of early upstream engagement allowed some actors (i.e., critical CSOs) to gain control over some formats and to broadcast their perspectives. These settings countered mainstream framings of risk and control, commercialization, social progress, or efficiency, and opened up the discourse, at least temporarily, as they allowed for exploring alternative pathways (cf. Sykes and Macnaghten 2013). Yet, upstream engagement formats also bore the risk of losing momentum because of the waning interest of actors and the difficulty to achieve impact. Instead, closed down perspectives proved more effective for some actors to reach their goals.

From a bird's eye's perspective, an increased variety of closed-down positions opens up the *landscape of perspectives*: it enriches the plurality of voices and stirs alternative closures of a debate. Thus, the rigidity of individual positions does not necessarily correlate with a reduced variety of perspectives. Yet, the dialogue becomes less balanced when perspectives solidify, resulting in difficulties to combine different settings of engagement, like invited and uninvited engagement. This is all the more the case if the setting moves closer to decision-making. Here the mainstreamed STI (governance) discourse strongly pre-frames how consequences of technologies are perceived. As a result, engagement settings are often closed down by inflicting techno-economic perspectives.

The timing of participation and societal engagement, as well as their proximity to decision-making, thus affect how issues are discussed and perpetuated. In upstream engagement, particular interests of actors often remain low; instead, when participating, actors tend to explore a range of arguments. However, even these imaginations of the issue at stake easily colonize future debates, as illustrated in my case studies where ethical arguments largely remained the same between different engagement formats.

In addition, especially in downstream engagement, the discourse on an issue often appears *fragmented*. This facilitates that aspects that do not fit are outsourced, such as ethical questions in contexts of risks. Moreover, pervasive structures like myths become elusive, while scientific approaches become more prominent. Yet, they potentially colonize the future just like myths. For instance, all my case studies maintained perceptions of prior technologies and approaches, potentially colonizing and closing down their future developments. To avoid this, the mechanisms that transfer perceptions of STI need to be deconstructed and properly reflected.

Furthermore, the positioning alongside the innovation stream affects how ethical aspects are introduced in the debate as introducing them in a non-disclosed way potentially colonizes the future. One counterstrategy is to address ethical aspects openly, yet this does not necessarily resolve the challenge altogether as literature indicates that the relation between 'upstream' and 'downstream' engagement is anything but linear. Upstream engagement hardly prepares for or impedes contestation further downstream (Felt and Fochler 2010). In the case of spontaneous inventions or unpredicted side-effects 'upstream' development and engagement may not even exist (von Schomberg 2013, von Schomberg and Blok 2019). Consequently, even if ethical issues are addressed openly upstream, how they shape the debate downstream still varies. Thus, their relation to engagement needs to be constructed in each case (Felt et al. 2009, 368).

As this short outline indicates, the issue of timing entails consequences for the organizational form of engagement, i.e., invited or uninvited engagement. Organizers and practitioners need to consider that formats as well as the relevance of ethical aspects shift along the innovation stream and affect opportunities for opening up or closing down. Combining different forms (and formats) of engagement is one strategy to enable a comprehensive reflection on STI. Moreover, such a combination challenges the reductionist assumption that upstream engagement effortlessly resolves downstream contestations. Instead, ethical or normative contestations can easily rise anew or take a different shape at different points of time. Awareness for this variability of (ethical) issues may ease to initiate participation and societal engagement activities.

9.2.3. Construction of actor roles: between imagined and emerging publics

The construction of actor roles considerably shapes how participation and societal engagement activities are conducted. This thesis confirmed that participation and societal engagement activities constantly reproduce actor roles and ideas of how governance should be conducted. As these ideas only shift slowly, *actor roles often remain consistent*, irrespective of their construction. One example for this is the deficit model which is frequently reinforced in analytical and participatory approaches alike (Chilvers 2008, 177, Irwin 2001, Wynne 2005). The construction of roles concerns all actors, including the lay public, stakeholders, and experts and is shaped by issues of timing and engagement formats.

When engaging the public, early-upstream engagement is generally *invited*; it is conducted on the assumption that a latently interested public needs to be mobilized to open up STI and STI governance. However, other concepts of engagement require different constructions of the public: downstream, *mediated engagement* allows for inviting actors with their specific perspectives and expertise for collaboration, reducing procedural complexity; and the concept of *emerging publics* is considered to evoke public interests and concerns more authentically. For each construction, my case studies presented examples and outlined implications for the role of the public.

Similarly, expertise can take different roles in engagement. In the literature expertise is often seen as closing down, as it brings along a dichotomy between technocracy and deliberation. In this case, technocracy is led by expertise and dogmatism, while deliberation considers a broad(er) range of actors, issues, and values. However, expertise can also be understood as an expression of democratic reason (Moore 2017b, see also section 2.2.2). My case studies showed *different roles for experts*: they appeared as organizers and initiated and framed invited engagement activities upstream; they provided alternative expertise for decision-making; or participated in expert deliberation. With the exception of CSO representatives, who were assigned both an expert status (alternative expertise) and being part of the public (organized public), responsibilities were clearly distinguished between actor groups, i.e. between (lay) public and experts.

Constructing experts as different from the (lay) public actively maintains a distinction between societal realms like 'science and policy' or 'science and public'. In so doing, it perpetuates a division of labor between innovation and responsibility, or between policy and expertise. STS studies have discarded such distinctions and argue that they prevent the integration of responsibility and innovation (e.g., Krabbenborg 2013).

Thus, the construction of actor roles reproduces wider understandings of how the social and technical realm interrelate. Actor roles are not fixed but depend on the respective situation. However, in practice, this is often not well reflected. To better integrate innovation and responsibility, organizers need to better explore how actor roles contribute and are subject to opening up and closing down more thoroughly. By so doing, they will add a new layer of opening up to individual settings as well as overall discourse.

9.2.4. Framing: the ultimate key for opening up?

Framing orients governance activities, including participation and societal engagement. Therefore, it is crucial for opening up and closing down as it affects who is supposed to participate in processes, and in what way. Opening up is constituted by actors' opportunities to reframe issues and to shape debates; next to individual engagement

settings, this reframing also affects STI and STI governance more broadly (see e.g., Rossignol, Delvenne, and Turcanu 2015, Ahlqvist and Rhisiart 2015).

Framing has tremendous consequences for dialogue. To engage consistently, actors need to *accept the framing* of an activity to stay involved. Remember how in my case studies actors withdrew from engaging when they had not collectively agreed on the framing, but opened up the debate by introducing their own. I found that the normative dimension is never fully concluded, and that framing has the power to include or exclude actors from engagement settings (cf. Sulmowski 2017, citing Wynne 2001, Wynne 2003, 2005, 2007).

Again, as with purpose and scope, or timing, the proximity to decision-making determines the likelihood of (temporary) closure. In general, the more concrete the application context, the more challenging it is to keep the framing open and all parties involved. The pressure to adhere to a specific (policy) framing gets stronger the closer activities move to decision-making. Hence, in any attempt to foster opening up in STI governance, it is crucial to rethink the framing at hand.

Overall, shifts in governance structures only occur slowly and are difficult to maintain; and individual attempts are frequently overruled. Indications for such shifts often remain sporadic, as they did in my case studies. I also found that patterns and routines of STI (governance) open up in a fragmented way. Consequently, to open up STI governance requires a range of engagement practices, while still allowing for closure where needed. My findings strengthen the argument that neither opening up and closing down need to be complete to have an effect on STI governance (Stirling 2008).

For the practice of participation and societal engagement in innovation, this implies that sounding out the margins for reframing a debate determines the possible scope of opening up and closing down. In invited engagement, allowing for participants to reframe the issue at stake in a way that makes (more) sense to them allows the debate to be opened up. At the same time, the policy and governance processes that these engagement activities feed into need to accommodate the results of these activities without pre-framing them.

On a final note, it retrospectively occurs to me that my thesis itself is framed in a *technology-centered way*. After all, my case studies start with a technology in the first place and then, secondly, with questions about public perceptions and needs. In this way, the whole idea of participation in innovation is already closed down to a certain extent. It is possible that using a goal- or problem-centered framing of my case studies would have opened up the respective debates even more. Such a take on the matter was impeded by the set-up of the projects in which I participated. In this way, I was thus unwillingly complicit in maintaining a governance discourse framed in a techno-economic way, despite the substantial attempts of opening up. This demonstrates the perseverance of established governance discourses (here: on technologies) and illustrates how power structures become constantly reproduced.

With this thesis, I intended to unlock participation in STI governance by investigating the *dynamics of opening up and closing down*. By tracing the social, epistemic, and normative dimensions in different engagement settings, I examined how opening up and closing down constitute in myths, in debates, in computational modelling. Ideally, one would consistently follow one single technology along the (imagined) innovation stream in real-time. However, this would exceed the scope of a PhD thesis by

far as it would take years at best. As an approximation, my approach allowed to investigate different stages of various emerging technologies to explore how their handling is integrated and normalized in STI governance. It only covered a variety of forms aimed at opening up, but managed to remained sensitive to wider conditions of STI governance as well. Thus, my thesis aimed at providing reflection on enabling and constraining agency, in particular in the context of R(R)I.

Such a reflection is necessary as opening up and closing down are never single-vector developments but take shape in multiple forms. These forms require careful consideration of how debates are opened up or closed down *before and after* participants get involved. In this respect, I argue in favor of a reflective approach towards opening up and closing down, and for maintaining a diversity in efforts to address how agency is enabled or constrained in STI governance. In other words, unlocking participation requires more than one key.

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Appendix: Method and analysis of literature review

To anchor my thesis, I developed a specific search strategy on opening up and closing down. This was necessary as exploratory searches in literature databases provided a random selection of articles.

Database

For my search strategy, I used the literature database Scopus. While other databases may show a better representation of social sciences, I dismissed them due to reasons of access, e.g. Ulrich's extensive periodical directory, or transparency, e.g., Google scholar (Mongeon and Paul-Hus 2016).

In a comparison of Scopus and Web of Science (WoS), the two most widely used databases for scientific literature, Mongeon and Paul-Hus (2016) find that Scopus shows a better coverage of journals in general (2016: over 20.300 compared to about 13.600) as well as a higher share of Social Science journals (2016: about 28% versus 21%) (Mongeon and Paul-Hus 2016). In addition, Scopus covers almost all Web of Science journals in the area of social sciences (SS, Figure 5). Therefore, I considered Scopus a good choice for the present literature review.

However, both Scopus and WoS show certain biases. First, they are biased concerning the coverage of research fields as they mostly cover journals from the natural sciences and biomedical research. Moreover, they show a clear bias with regard to English journals as well as geographical distribution. Journals published in the United States, the United Kingdom, the Netherlands, France, Germany, and Switzerland are clearly overrepresented in both databases (Mongeon and Paul-Hus 2016).

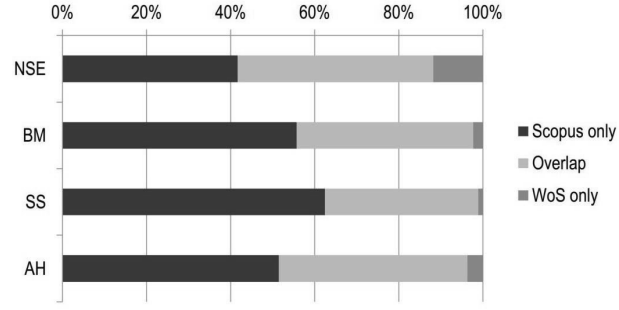

Figure 5: Coverage overlap between Scopus and Web of Science

Source: Mongeon and Paul-Hus (2016, 220),
reproduced with permission from Springer Nature

However, for my thesis, these biases are of limited relevance. As my foreign language skills are restricted to (mostly) English, the overrepresentation of English-speaking journals does not pose an additional limitation to the review – beyond my own. Regarding the geographical bias, Mongeon and Paul-Hus (2016) criticize that Scopus' coverage discriminates journals that are published outside Europe or the US. This is a fundamental shortcoming of the literature database and should be improved.

Yet, my thesis is based on case studies set in the geographical realm of the European Union and concerning research projects funded by the European Commission or Austrian research funders. Thus, the case studies are embedded in regulatory, political, and cultural landscapes within the European Union, and rely on Eurocentristic perceptions of science and technologies from the outset. While a look at from outside of Europe on European funding structures and the resulting projects would be worthwhile (and journals not published in Europe or the US may provide such a perspective), I accepted this geographical bias for the literature review and my thesis.

Defining a search strategy: following Stirling (2008) in the literature

To find a balance between accuracy and comprehensibility of the search results, search strategies need to be developed carefully. Scopus allows selecting documents and "following" them in the citations of other publications via citation analysis, which examines the frequency, patterns, and graphs of citations in documents. This is the approach I chose to follow Stirling (2008).

To ensure feasibility and high accuracy of the results, I focused on this one publication rather than including Stirling's complete work in this analysis. Moreover, as journal articles are the best represented type of document in databases, I decided to focus on the article of 2008 rather than putting the prior book chapter at the center of my search (Stirling 2005).

In addition, I reduced the selection of documents citing the article by the following parameters:

- Period: The search covered the years 2008 to 2020. I chose 2020 as the endpoint of my search to ensure a stable body of literature. Accordingly, the latest literature on Stirling is not included systematically in the review.
- Language: English, for practical reasons.
- Source: Journal Articles.
- Type of documents: Articles and Reviews, as these two types of documents usually provide the most comprehensive bibliographic metadata.
- Subject area: for more accurate results regarding research questions and manageability, I excluded a few subject areas from the search: Business, management and accounting (176 articles), Economics, econometrics and finance (91 articles), Biochemistry, genetics and molecular biology (41 articles), Nursing (12 articles), Immunology and microbiology (4 articles), Health professions (2 articles).

The remaining 388 articles were refined manually by screening their abstracts. Reasons for exclusion were: no abstract available or a strong focus on politics (warfare, crisis management, etc.). Moreover, I excluded articles without a clear link to emerging technologies (e.g., parts of conservation biology, ecosystem services, community work, volcanology, …) unless they brought a conceptual discussion of Stirling (2008) to the table. The final corpus of 290 articles was screened manually to select core publications (see Chapter 3). During working on my thesis, I identified and included individual articles via snowball system that proved relevant for a conceptual discussion beyond the concrete context of emerging technologies, as well as literature published after the end date of the systematic review.

Sketching out Stirling's reception quantitatively

Scopus provides tools to indicate Stirling's reception in wider literature. It allows for analyzing search results according to different criteria, like documents by year, authors, affiliations, funding sponsor, source (journals), and subject area or type of publication. I will not in detail discuss all of them but focus on the ones that I deem most interesting for the present thesis.

In general, Stirling's article is well received among STS and sustainability scholars: my research and refinement strategy resulted in 290 publications citing Stirling (2008). Figure 6 indicates an overall steep increase in publications citing Stirling, despite individual years where interest or at least citations declined. The sharp rise in 2015 remains unresolved when screening the documents. One guess is that citations rose due to an increasing interest in issues like R(R)I; however, this remains unverified.

When looking at the main authors citing the paper, a few authors seem to cite the article regularly (among them Stirling himself). The first 10 authors account for 47 publications of the corpus (about 19%). I take this as an indication that the article is well-received among a broad variety of authors, and explored in a variety of different fields and research questions (Figure 7).

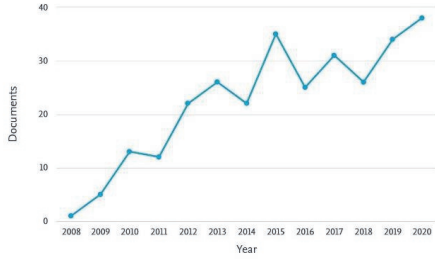

Figure 6: Documents per year citing Stirling (2008)

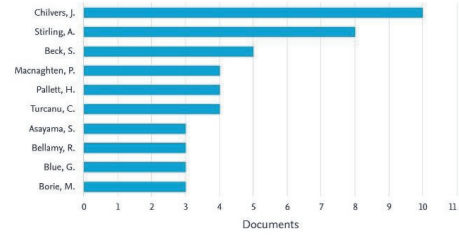

Figure 7: Documents per author

This is further solidified when looking at the subject area profile of the search (Figure 8). Main areas of citing the article are Social Sciences (207 publications, about 35%) and Environmental Sciences (167 publications, about 29%). The other subject areas range broadly from Energy (46 publications, about 8%) to Computer Sciences (10 publications about 2%). Subsuming Energy under Environmental Sciences, and integrating them with Social Sciences, they account for about 70% of the literature body. The prominence of Social Sciences as well as Environmental Sciences indicates a transfer of conceptual to practical discussions of social appraisals of technologies.

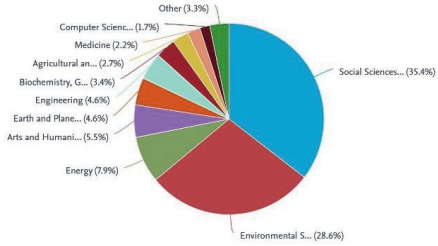

Figure 8: Documents by subject area

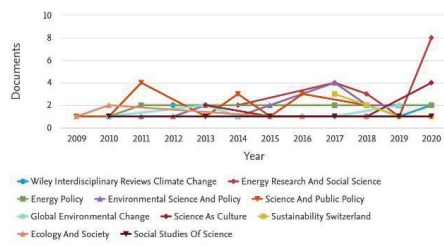

Figure 9: Documents per year by source

Looking at Energy individually, its prevalence (7,9%) illustrates the importance of the topic in policy and (social) sciences for the discussion of a transition toward green energy. Moreover, this is indicated by a steep rise in document numbers in Energy Research and Social Science (Figure 9).

Altogether, the article is cited in 140 journals and thus, broadly received among research communities. However, 103 out of the 290 articles (35.5%) are published in only 10 journals. Yet, for all these analyses one needs to keep in mind, that the scale remains rather small. Even the steep increase in *Energy Research and Social Science* only accounts for eight articles in 2020.

Part IV

Addendum

Summary

Social, scientific, and technical questions are closely intertwined: visions of a desirable future concern ethical and social values including questions of distributing (ecological and economic) risks, solidarity and social cohesion, fairness, equality and justice. Accordingly, technologies not only need to fulfill specific tasks but instead touch upon questions of responsibility and of reaching societal acceptance (Owen et al. 2013, von Schomberg 2013).

Technologies, especially new and emerging technologies like nanotechnologies, synthetic biology or artificial intelligence are ambiguous in the expectations they evoke (for analyses of the social life of expectations see e.g., van Lente 2012, Borup et al. 2006, van Lente and Rip 1998), and accommodate a range of different value-laden perspectives and patterns of moral argumentation (Swierstra 2017, cf. Swierstra and Rip 2007).

In STI governance, exchanging viewpoints and appreciating resulting options constitutes an important strategy to overcome this ambiguity. Accordingly, engaging stakeholders and the wider public became in vogue to ensure a comprehensive reflection of technologies, to better align them with societal values, and to address and counter democratic deficits in technological development (e.g., Burri 2018, Chilvers and Kearnes 2016, Owen et al. 2013, Kearnes, Macnaghten, and Wilsdon 2006, Stirling 2008). In short: one could think of participation and societal engagement as a way to *unlock* how we design STI governance.

Indeed, societal engagement with emerging technologies features several pertinent promises. It sets out to enhance social robustness of decisions and to ease democratic shortcomings of STI governance and promises a more inclusive process compared to scientific analysis by offering a more comprehensive variety of perspectives, e.g. in policy advice (Delgado, Kjølberg, and Wickson 2011, Stirling 2008). Thus, societal engagement constitutes a popular strategy in technology policy, STI governance, and innovation more generally to arrive at widely acceptable and accepted decisions, and to ensure innovation (Owen, Macnaghten, and Stilgoe 2012, van Mierlo, Beers, and Hoes 2020). Moreover, it is supposed to strengthen agency with regard to STI governance. This is where my thesis sets in.

In this thesis, I study the dynamics between opening up and closing down. In particular, I look at how different forms of participation and societal engagement allow for *opening up and closing down in STI governance*.

To do so, I structure my thesis in the following way: After introducing the overall problem outline, as I did above (*Chapter 2*), I introduce my conceptual approach in *Chapter 3*. Inspired by Andy Stirling, I understand opening up as consistently considering a broad range of actors, perspectives and values in STI governance and closing down as a reduction thereof. Unlike Stirling, I explore opening up and closing down as empirical phenomena, rather than normative, and thus *per se* desirable, steps of STI governance. Opening up and closing down manifest in dialogue, but show occur on different levels as well. Accordingly, I extend my analysis from dialogue to levels of public sense-making as well as affordances. I use three dimensions – social, epistemic and normative – to make the interactions of opening up and closing down visible and to investigate how they enable or constrain agency, assuming that disentangling these dimensions allows for delving deeper into the dynamics between opening up and closing down.

Chapter 4 outlines my research approach: I selected a case study approach to cover different moments of innovation, based on the analysis of documents, interviews and focus groups. Accordingly, my case studies address a broad variety of technological approaches and mechanisms with regard to opening up and closing down: I discuss myth formation as public sense-making in the context of neuroenhancement (Chapter 5), the engagement of civil society organizations in dialogues on synthetic biology (Chapter 6), and affordances of computational modelling for nano risk governance (Chapter 7).

Chapter 5 looks at public sense-making in the context of neuroenhancement: it investigates how unfamiliar technologies are familiarized in public debates by mobilizing the concept of 'technology myths'. Based on empirical data from upstream engagement on the governance of neuroenhancement, it elaborates on the mechanisms through which public myths emerge. My colleague and I explored technology myths as a mechanism to transfer meaning via technology comparators. By so doing, actors create a specific picture of a technology by selectively highlight some of its traits while omitting others. As a result, the technology at stake, or related practices, are interpreted in different ways. In the case of neuroenhancement, they span from a harmless daily routine ('drinking coffee') to illegal practices ('taking drugs'). With this case study, we show how narratives are performative and offer different interpretations of complex technical issues, while these interpretations affect how the public perceives technologies (e.g., neuroenhancement) down the road. Thus, looking at narrative structures such as technology myths allowed gaining insights into the formation of public perspectives about technologies.

Chapter 6 compared different settings of civil society organizations' engagement ('CSO engagement') by analyzing their actor roles, formats, and framings in relation to synthetic biology. The first setting was a public protest against household products that (potentially) contained synthetic biology components to substitute palm kernel oil; the second was triggered by this conflict and featured an invited multi-stakeholder deliberation process; the third was organized under the premises of upstream engagement of R(R)I. Thus, the settings ranged from early-upstream engagement to downstream reactions to ready-for-market products, contrasting invited engagement with other forms of engagement, i.e., protests as explicit political activity to alter decision-making on a specific topic. This case study compared different forms of dialogue, and looked at how different conditions shape and are shaped by CSO engagement. CSOs did not engage in all settings in the same way or for the same reasons. In particular, to hold framing power and to see real-life impact of their activities turned out to be crucial for CSO engagement. Consequently, they hardly engaged in settings they perceived as pre-framed in a way that contrasted their agendas. However, looking at STI governance as a whole, we concluded that a variety of engagement formats under different framings enhances the societal competence and capacity for comprehensive reflection on synthetic biology.

Chapter 7 investigates how a specific computational modelling tool affords understandings of risk governance in interdisciplinary collaborations. Generally speaking, affordances limit the way how (virtual) artifacts are used, i.e., close down discourse through material conditions. They perpetuate specific understandings of issues at stake, like risk or sustainability, and accommodate potential user choices. Thus, we reconstructed how the tool affords actor constellations, concepts, and the imagined contexts of using the tool, in particular in relation to R(R)I. By so doing, we explored virtual manifestations of discourse in the context of computational modelling, in particular

the shifts in discourse they afford. My colleague and I found that next to disciplines conventionally engaged in risk assessment and management, expertise for responsible innovation supported to move towards 'sustainable manufacturing'. The tool extended its scope by incorporating shifts related to findings on nanomaterials themselves, as well as additional analyses, such as socioeconomic analyses and undertook enormous efforts of engaging a range of actors. Yet, opening up its scope and the actors involved in its development as required by basic research also put the tool at tension to industrial applications, which again affected its overall tendency to open up.

Subsequently, *Chapter 8* follows the three dimensions in all three case studies individually and in cross-case comparison. I argue that first, aspects of the social dimension dominate the discussion in the literature on opening up and closing down. Between the three dimensions, it is also the best reflected by practitioners in the field. This is because the social is expected to approximate varying epistemic and normative input as it is considered to embody knowledge and values. However, my analysis shows that this approximation does not necessary hold. Opening up and closing down in the epistemic or normative dimension do not automatically respond to a wider or narrower range of actors involved, although such tendencies exist.

Second, I found that the epistemic dimension is the most variable between all three in terms of how it manifests. Whether it is established through narratives or various kinds of data depends on the position of each case study in the innovation stream, as well as their overall normative setting. Yet, in individual situations, specific epistemic input shifted the overall normative scope of the case study, at least to a certain degree.

Third, the normative dimension dominated all my case studies, and defined the social and epistemic dimension of my case studies. If it is closed down completely, shifts in the social or epistemic dimension would not show any effects. Thus, I consider the normative dimension the most crucial for opening up and closing down.

Moreover, it carves out the specifics of public sense-making, dialogue, and affordances with regard to opening up and closing down. Very briefly put, public sense-making gains a double function as exploring and sharing a range of interpretations of technologies. Dialogue strengthens this emphasis of exchange, placing emphasis on the relations between different actors and on learning on eye-level. Affordances, again, highlight durable features of discourse and introduce a certain rigidity of structure and qualities. Thus, each of these mechanisms shapes how the opening up and closing down are performed.

Finally, in *Chapter 9*, I present concluding remarks, and discuss conceptual as well as practical implications of my work. With regard to the latter, I argue that the normative dimension cannot be closed down fully. Likewise, my findings on epistemically induced shifts in the normative dimension suggest that its closure remains relative, rather than absolute. This implies that core issues of contestations are value-based and therefore show a tendency to prevail, irrespective of the social or epistemic peculiarities of the respective situations. As a result, closing down of a debate is *per se* impossible; instead, closure itself remains temporary, based on a more or less (technically) stabilized discourse, i.e., compromise between actor positions.

My thesis aims at providing reflection on enabling and constraining agency, in particular in the context of R(R)I. Such a reflection is necessary as opening up and closing down take shape in multiple forms and require careful consideration of how debates are

opened up or closed down *before and after* participants get involved. In this respect, overall, I argue in favor of a reflective approach towards opening up and closing down, and for maintaining a diversity in efforts to address how agency is enabled or constrained in STI governance as unlocking participation, in my understanding, requires more than one key.

Impact paragraph

How to govern science, technology and innovation (STI) has been a central question for policy and society altogether, in particular in context of new and emerging technologies. Who is to have a say in STI development and governance and under which circumstances, is one of the core questions in STI (governance). It affects how we think about and act in innovation, and by extension, society altogether: our ideas about desirable futures are intrinsically interwoven with ideas of how to innovate - and to what end.

This is where this thesis steps in: Looking at *technical innovation*, new and emerging technologies promise new desirable ways to solve problems of our time. Yet, they pose considerable challenges for STI policy and governance. Due to their unknown consequences, the risk for public contestation is high – a delicate situation for STI governance. My thesis analyses and compares three emerging technologies – nanotechnology, synthetic biology, neuroenhancement -, all of which were expected to trigger extensive social debates at the time. Suspected to generate a need for (new and adapted ways of) governance, these technologies constituted a playing field to explore new governance concepts like R(R)I. Here, integrating society's perspectives has become crucial for shaping innovation, affecting every-day lives as well as the daily work of academics, researchers, and practitioners through practices of participation and societal engagement.

In particular, I am interested in phenomena of opening up and closing down in the context of governing emerging technologies, mostly, but not exclusively, in relation to participation and societal engagement. Reflection on unrestricted practices of 'openness' – in terms of participation and others – has increasingly entered the academic discourse. I contribute to this discussion by deconstructing current practices in the light of opening up and closing down, to help further the debate on appropriate, just, transparent and reasonable approaches to innovation, including participation and societal engagement and STI governance overall. Focusing on opening up and closing down allows to move the spotlight away from individualized approaches of participation and societal engagement towards the *structures* that enable or constrain agency in this regard. By so doing, I aim at highlighting the complexity in which participation and societal engagement are embedded, and the scope that guides individual endeavors.

My thesis aspires to make several contributions in both academic and practical work and its results are relevant for at least three main target audiences – academia, practitioners, and decision-makers in policy.

Scientific impact of my work

With regard to scientific contributions, my findings are foremost interesting for researchers interested in STI governance, specifically of either one of the technologies I outlined (neuroenhancement, synthetic biology, nanotechnologies). On a conceptual level, researchers interested in questions of social sciences, in particular STS, or technology assessment can benefit from my findings. Part of my contribution here is to advance and refine the approach of analysis of well-acknowledged phenomena – opening up and closing down in STI (governance). I do so by not only considering participation and societal engagement in dialogue, but in additional manifestations in relation to STI – as narratives and sociomaterial aspects (i.e., myths, affordances). Therefore, I actively span between different conceptions of discourse and strengthen attempts to expand conventional

understandings of dialogue - and by extension, the conditions that shape agency, i.e., opening up and closing down.

Moreover, I differentiate between different dimensions – the social, epistemic and normative – and made their convergence and divergence visible. By disentangling these three dimensions, I am able to delve deeper into the dynamics between opening up and closing down and to focus on their empirical rather than their normative quality. I argue that the social is widely discussed in literature and the epistemic is the most flexible among the dimensions. However, it is the normative dimension that dominates the dynamics between opening up and closing down. Consequently, focusing on the values involved in technology conflicts, rather than on epistemic aspects only, may help to disentangle lines of contestations. This is all the more interesting as the normative dimension cannot be closed down entirely. Consequently, STI governance of emerging technologies, including participation and societal engagement, *necessarily* remains open for re-negotiation. By following my approach in relation to three different emerging technologies, I provide new insights on the governance of emerging technologies and how agency becomes enabled or constrained in this context.

Practical insights of my thesis

Besides a scientific impact, my thesis also contributes to practical insight in the organization of participation and societal engagement. Here, practitioners and organizers of participatory processes, be it from research, innovation or policy, can benefit from my reflections to become better aware of potential pitfalls when conducting participation or societal engagement. For this, this thesis addresses challenges and unresolved aspects in relation to purpose and scope, timing and organizational form, actor roles, and framing, and provide practical remarks to support reflective practices of participation and societal engagement.

First, with regard to purpose and scope, organizers need to reflect on the proximity of the case to decision-making, affecting its flexibility in scope. This allows for expectation management without compromising its transparency and legitimacy. Second, timing and organizational form are closely intertwined, and again depend on the case study's proximity to decision-making, as well as its position along the innovation stream. To ensure a comprehensive reflection on STI, organizers and decision-makers need to appreciate and combine various forms of engagement, such as invited and uninvited engagements. Third, the construction of actor roles reproduces wider understandings of how the social and technical realm relate to each other. Practices of participation and societal engagement need to reflect more comprehensively on the implications of this situatedness to better integrate considerations of innovation and responsibility, and deriving impacts of opening up and closing down. Fourth, reframing issues allows for opening up, yet, is frequently restricted by the proximity to decision-making. Inducing different framings simultaneously supports opening up of STI (governance) in a fragmented way and still allows for closure where needed.

My thesis aims at supporting reflection on the structures that enable and constrain agency and to move towards systematic perspectives on participation and societal engagement. Policy decision-makers benefit from these reflections in planning governance processes: here, being more mindful with regard to trade-offs between opening up and closing down is crucial when it comes to designing and implementing (STI) governance

and participatory processes. In particular, reflection on the open-endedness of processes and on how to frame activities to mobilize specific publics, could still be strengthened in practice. Accordingly, how we conceptualize issues will affect how wider society is able to contribute to STI governance.

Dissemination and outreach of my results

To engage with the scholarly community, I have published two co-authored articles in peer-reviewed journals, one more article is to be submitted soon. Also, I have co-authored five more articles that closely relate to the case studies of my thesis (see below). The results of the projects that my thesis is based on, have been published online as project deliverables (see respective websites). In addition, I am co-editor of a special issue of the Journal of Responsible Innovation ("Into the wild: Futures and Responsibilities in Technology Assessment", Volume 4, Issue 2, 2017 pages 83-315), where one of my case studies was published. To present the special issue, I organized two sessions for the authors at the S.Net 2017 at Arizona State University/USA. Moreover, during the five years of my research, I co-organized national conferences (e.g., the annual conference of ITA) and sessions at national and international conferences (e.g., STS Graz 2020/21, 4th European TA conference 2019 in Bratislava/Slovakia, 3rd European TA conference 2017 in Cork/Ireland), and had the chance to attend a few more (including EASST 2022 in Madrid/Spain, EASST4S 2020 in Prague/Czech Republic, NTA8 2018 Karlsruhe/Germany, SNet 2018 Maastricht/Netherlands, SNet 2016 Bergen/Norway, EASST4S 2016 Barcelona/Spain[34]).

My main effort to reach out beyond the scholarly community was to publish numerous communication briefs (EU policy briefs, ITA dossiers, NanoTrust dossiers) about the projects that I was involved in (and thus on my thesis in a wider sense). These briefs addressed politics (Members of Parliament), policy and authorities, as well as a more general public. Through these efforts, I hope to initiate widespread scholarly, policy, and public debates not only on participation and societal engagement, but on how to govern emerging technologies more broadly.

[34] Technically, the last two took place before the official start of my PhD, but were already related to the projects that my thesis is based on. Therefore, I listed them as well.

Additional publications related to the topics of my dissertation

Bauer, Anja, Capari, Leo, Fuchs Daniela & Udrea, Titus (2023). Diversification, Integration and Opening: Developments in modelling for policy. *Science and Public Policy*, scad038, https://doi.org/10.1093/scipol/scad038.

Bauer, Anja & Fuchs, Daniela (2023). Modeling for nano risk assessment and management: The development of integrated governance tools and the potential role of technology assessment. *Tatup - Technikfolgenabschätzung. Theorie Und Praxis*, *Modeling for policy: Challenges for technology assessment from new prognostic methods*, 18-23. doi:10.14512/tatup.32.1.18.

Bauer, Anja, Bogner, Alexander & Fuchs, Daniela (2021). Rethinking societal engagement under the heading of Responsible Research and Innovation: (novel) requirements and challenges. *Journal Of Responsible Innovation*, *8 (1)*, 1-22. doi:10.1080/23299460.2021.1909812.

Fuchs, Daniela, Bauer, Anja & Bogner, Alexander (2021). Nur kein Protest? Eingeladene Partizipation und Bedingungenzivilgesellschaftlicher Beteiligung. In R. Lindner, Decker, M., Ehrensperger, E., Heyen, N. B., Lingner, S., Scherz, C., & Sotoudeh, M. (Eds.), *Gesellschaftliche Transformationen - Gegenstand oder Aufgabe der Technikfolgenabschätzung?* (pp. 219-230). Baden-Baden: nomos. Retrieved from https://www.nomos-shop.de/titel/gesellschaftliche-transformationen-id-86476/

Fuchs, Daniela, Capari, Leo & Torgersen, Helge (2018). Neuroenhancement und TA-Verantwortung. (M. Decker, Lindner, R., Lingner, S., Scherz, C., & Sotoudeh, M., Eds.), *NTA7 Proceedings: "Grand Challenges" meistern – der Beitrag der Technikfolgenabschätzung*. Baden-Baden: Nomos – edition sigma. Retrieved from http://dx.doi.org/10.5771/9783845283562-11.

About the Author

Daniela Fuchs (Linz/Austria, 1987) studied Human Ecology/Biology (MSc) at the University of Vienna (Austria) and the Free University of Brussels (Belgium), as well as history (BA) at the University in Vienna (Austria).

After obtaining her degrees, she started her academic career at the Institute of Technology Assessment (ITA) of the Austrian Academy of Sciences (2014-2020, 2021-2023). At ITA, her research focused on questions of governance, participation and societal engagement with regard to different emerging technologies (nanotechnology, neuroenhancement, synthetic biology, artificial intelligence) in national and international projects. Moreover, Daniela investigated practices of policy advice in various contexts: the institutionalization of technology assessment in Austria, the development of the Austrian nano risk governance system, the role of computational modelling in policy advice, and – lately – scientific policy advice in crises like the COVID-19 pandemic.

Before starting her PhD, Daniela spent Autumn 2017 as a short-term visiting researcher at the School for the Future of Innovation in Society at Arizona State University.

Between 2018 – 2024, she pursued her PhD as an external PhD candidate at Maastricht University. During this time, she participated in two summer schools of the training program of the Netherlands Graduate School of Science, Technology, and Modern Culture (WTMC, 2018, 2019).

In 2021, Daniela transferred to the University of Life Sciences in Vienna to work on the sustainability of emerging photovoltaics. Since January 2023, she continues her path as a researcher at the Centre for Social Innovation (Zentrum für Soziale Innovation, ZSI) in Vienna. Also, she teaches 'Technology in Society' (Bachelor of Electronics and Information Technology, since 2020) and 'Responsible Research and Innovation' (Master of Media and Human-Centered Computing, since 2021) at the Technical University of Vienna.

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