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The Limits of Responsibilization? Responsibility Boundary-Work Through Visions in the Case of Neuromorphic Computing

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Abstract Visions and imaginaries have been longstanding research topics in Science and Technology Studies. Visions of sociotechnical change often ascribe responsibility for achieving the desired change to specific actors. However, there is little research on how visions create, change, and preserve responsibilities in the present. Drawing on Vision Assessment, we present a case-study on visions of neuromorphic computing in NeuroSys, a research and innovation cluster located in the Aachen region in Germany, which develops brain-inspired computing technology, also known as neuromorphic computing. Based on interviews, participant observation, and document analysis, we identify a core vision, which imagines the region as a prominent center of neuromorphic computing, and three satellite visions, focusing on, respectively, entrepreneurship, science, and society. We analyze all visions through the lens of "responsibility boundary-work" operating in the dimensions of time, space, and actor constellation. This concept captures the selective conferral and deferral of responsibilities through visions, highlighting how normative boundaries are drawn in local practices. We further shed light on the larger institutional conditions shaping responsibility boundary-work by attending to the "politics of visions." Power struggles are enacted through the ways in which visions confer and defer responsibilities. Tensions between these practices reflect conflicts over desirable social orders and power distributions within them, revealing the socio-political nature of visions. We discuss the implications of these findings for governance approaches that pursue responsible research and technology development, and we conclude that responsibility boundary-work may limit the potential of governance to conceive of and work toward responsible futures.

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Introduction

Visions of the future are frequently evoked in science, policy, civil society, and mass media to outline the potential of technology for responding to global challenges and initiate social transformation (Heil et al. 2022). For instance, national artificial intelligence (AI) strategies construct visions of AI as both inevitable and uncertain while allocating resources to stabilize imaginaries of "national AI" and promote the materialization of corresponding constructed futures (Bareis and Katzenbach 2022). In Science and Technology Studies (STS), the performative role of future visions and imagination in enabling new forms of social cooperation, driving technology development, and preordaining sociotechnical change has been a longstanding research topic (Adam and Groves 2007; Borup et al. 2006; Beckert 2016; Birch 2017; Merton 1957; Roberson 2021). Vision Assessment in Technology Assessment (TA), drawing on such theoretical accounts, analyzes circulating visions in practical contexts, such as research projects, to uncover normative and epistemic assumptions, to give advice to publics and policymakers, and to interactively shape more desirable visions (Lösch et al. 2021).

So far, however, scholars have paid little attention to how visions create, change, or preserve responsibilities (e.g., for taking the lead in sociotechnical change). Understanding the making and unmaking of responsibilities through visions is relevant for a broader set of governance approaches, including TA (Böschen et al. 2021; Rip and Robinson 2013), anticipatory governance (Barben et al. 2008), (post-)ELSI (Ethical, Legal & Social Impacts) and ELSA (Ethical, Legal & Social Aspects) programs (Balmer et al. 2016; Ryan and Blok 2023; Zwart et al. 2014), as well as Responsible Innovation and Responsible Research and Innovation (Fisher et al. 2024; Owen et al. 2013; von Schomberg and Hankins 2019). These various approaches seek to align scientific research and technology development with societal values, concerns, and needs. In so doing, their proponents examine and intervene in research and development to capture and "modulate" (Fisher and Schuurbiers 2013) existing responsibilities, in particular those of technoscientific experts (Glerup 2015; Glerup et al. 2017; Lee et al. 2019).

Some authors have analyzed the role of visions in creating or reforming multiple forms of responsibilities in and for technology development (Grunwald 2017; Lösch et al. 2019b), claiming that visions can result in a process of "responzibilization" (Lösch et al. 2017). Schneider et al. (2021) used collaborative scenario-methods to modulate visions on 3D-printing and thereby promote responsible research and innovation. Urueña (2023: 7) describes "governance mechanisms through visions" as a critical dimension when it comes to "using the future" for the governance of science, technology, and innovation. While these studies focus on the alteration of existing responsibilities or the creation of new ones, it has remained understudied how visions can also limit such expansive or reformative tendencies. Understanding this limiting capacity is relevant to better understand if and how visions could become a vehicle of Responsible Innovation and Responsible Research and Innovation, here abbreviated as R(R)I.[1] Building on Vision Assessment in TA, we adopt a praxeological standpoint, proposing that future visions are socio-epistemic practices through which actors can change, preserve, or in other ways affect the present (Lösch et al. 2019a, b).

This article empirically traces such socio-epistemic practices in the context of a research and innovation cluster called NeuroSys, which is based in the Aachen region in Germany. NeuroSys bundles expertise from researchers, business leaders, and regional stakeholders to develop, produce, and commercialize neuromorphic computing hardware as well as corresponding software for Artificial Intelligence (AI) applications. The architecture of neuromorphic hardware emulates the human brain to achieve higher performance and improved energy-efficiency in comparison to established microprocessors (Prytkova and Vannuccini 2022). The cluster tends to be framed as contributing to sustainability (in particular, sustainable AI), European technology sovereignty, and the region-specific transition process of structural change after the phasing-out of lignite mining, on which the region depended economically. For this reason, NeuroSys is closely entwined with the ongoing (and envisioned) regional transformation. The cluster is faced with questions of how it should relate to regional transformation processes and who should (not) be responsible—or who should *respond* to these questions.

Given this context, our analysis in this article is devoted to visions as mediators of what we will call *responsibility boundary-work*. To describe and understand this process, below we introduce in the section "Theoretical Background" the concept of *responsibility boundary-work* as derived from a review of the literature on socio-technical imaginaries, Vision Assessment, and boundary-work. Next, in the section "Case-Study on Visions of Neuromorphic Computing in NeuroSys", we present our empirical case in more detail, highlighting the multifaceted networks and technical as well as social conditions for situating neuromorphic computing in the Rhenish Lignite Area. Setting the stage for our empirical study on responsibility boundary-work through visions, we introduce our "Multi-method Approach to Vision Assessment." Based on an empirical analysis, we next carve out a *core vision* and three distinct *satellite visions,* which diverge in the analytic dimensions of time, space, and actor constellation, as well as give rise to different forms of responsibilization ("Empirical Analysis"). The concept of responsibility boundary-work sheds light on how actors in NeuroSys make use of visions not only to change or create responsibility, but also to preserve existing responsibilities or deflect responsibilization. Subsequently, we point out how these discriminatory practices are underpinned by what we call the *politics of visions*, that is, the clash of visions reflecting power struggles in the present and disagreements over desirable future social orders. Finally, in the last section we discuss the implications of our findings for governance approaches that pursue responsible research and technology development.

[1] We follow Smolka (2020) and Shanley (2021) in using the abbreviation R(R)I to bind together an intellectual movement often associated with the label of Responsible Innovation (RI) and the European Commission's Responsible Research and Innovation (RRI) public policy discourse.

Theoretical Background

Sociotechnical Imaginaries (STIs)

The concept of sociotechnical imaginaries (STIs), emerging from the co-productionist literature in STS (Jasanoff 2004a; Jasanoff and Kim 2009; Sismondo 2020), offers us a seminal way of theorizing how collective imagination shapes technological projects. The idiom of co-production stresses the inextricable link between knowledge and social order. Co-production is "shorthand for the proposition that the ways in which we know and represent the world (both nature and society) are inseparable from the ways in which we choose to live in it" (Jasanoff 2004b: 2). The concept of STIs is inspired by work in anthropology and political science, which argues that imagination is constitutive of the ability to create collectively shared interpretations of social reality (Castoriadis 1987), technoscience (Markus 1995), nations as "imagined communities" (Anderson 2006), modern democracy (Ezrahi 1990), and modernity itself (Appadurai 1996; Taylor 2004). Taking into account the disciplinary power of standardization and legibility to allow for more effective governance (Foucault 1975/1995; Foucault 1979/2008; Scott 1998), the concept highlights the intimate connection between technoscientific projects and political power. Jasanoff (2015: 3) defines STIs as "collectively held, institutionally stabilized, and publicly performed visions of desirable futures, animated by shared understandings of forms of social life and social order attainable through, and supportive of, advances in science and technology." STIs are thus special forms of future visions, which reflect technological projects in their relation to imaginations of community and right social order.

To qualify as an STI, a vision needs to be, by definition, firmly established on the institutional level, the public conscious and the collective understanding of social reality. Jasanoff (2015) explains that the "vanguard vision" (Hilgartner 2015) of small collectives, or even a single individual, can "rise to the status of an imaginary," but it remains unclear why certain visions do so and others not. Hilgartner (2015: 36) defines "sociotechnical vanguards" as "relatively small collectives that formulate and act intentionally to realize particular sociotechnical visions of the future that have yet to be accepted by wider collectives." As he argues, similarities and analogies between the "vanguard vision" and established imaginations or narratives—in his example, between computing and the emerging field of synthetic biology—play a key role in making vanguard visions compatible with established sociotechnical imaginaries, in this case the US as a technological powerhouse (ibid.). But Hilgartner's analysis, while paying attention to the process of making new visions compatible with existing imaginaries, does not include the practices that contribute to the making of a new (or the significant alteration of an existing) STI. The analytic potential of the STI concept, on the contrary, can be realized only after a fair level of stability and saturation has been achieved as a *result* of change, whereas it struggles to make visible the practices contributing to its own genesis. We therefore suggest that the evolution of an STI, i.e., an *STI-in-the-making,* should be studied by analyzing visionary practices.

Vision Assessment

Vision Assessment analyzes the role that visions of sociotechnical futures (e.g., scenarios, guiding visions) play in social processes, e.g., of innovation or sociotechnical change (Grunwald 2012; Lösch 2006; Lösch et al. 2019a, b; Lösch et al. 2017). To this end, Vision Assessment adopts a practice-focused approach, centering on visions in their use by actors. By reflexively feeding the results back into debates on technological futures, Vision Assessment contributes to the broader project of TA to provide decisionmakers with future-oriented, reflexive knowledge about the consequences of technology development and deployment (Böschen et al. 2021; Frey and Schneider 2022). The attempt to trace the impact of future visions on the present is expressed through the programmatic claim that "sociotechnical futures [are] shaping the present" (Lösch et al. 2019a, b). Sociotechnical futures, instead of pertaining to the future of technology as such, address the relationship between technologies in (imagined) future societies and the (imagined) role played by these technologies (Böhle and Bopp 2014; Ferrari and Lösch 2017). We can thus meaningfully speak of cultural, societal, anthropological, or even "past" futures, which become a medium of technology debate (Grunwald 2012).[2] The plural of "futures" makes the contested and pluralistic nature of these presently used visions explicit (Grunwald 2012). Breaking with perceived path dependencies[3] and distancing itself from technology-determinism, the talk of futures (as opposed to "the" future), stimulates "thinking in alternatives" (Dobroć et al. 2018).

Visions can translate between present and future constellations, can enable communication and coordination among different actors and discourses, and can activate (present) behavior, unfolding a "normative force" (Ferrari and Lösch 2017; Lösch and Schneider 2016). Importantly, for our discussion, visions are ascribed the potential to impact established *responsibilities:* to re-form existing responsibilities, to invent new responsibilities, or to create irresponsibility.[4] To describe these processes of responsibility making and unmaking, Lösch et al. (2017) introduce the concept of *responsibilization*. They define responsibilization as that which visionary practices "effect" and what is achieved when particular actors—to "enable, prevent, or realize an envisioned future"—are "discursively addressed as capable and in need of doing something" (2017: 139). By changing "sociotechnical arrangements," visions therefore "imply new distributions and ascriptions of the responsibilities that the actors would or should have in the envisioned actor-constellations of the future" (ibid.). As our analysis will demonstrate, however, responsibilization through visions can be

[2] In a similar spirit, Urry (2016: 15–33) described "Past Futures" and even wrote a "Brief History of the Future."

[3] As Sigl and Leišytė (2018) argue, diverging STIs play a substantial role in sustaining path dependencies in science and innovation management. Reformers of science and technology should therefore pay attention to imaginaries and, in particular, which practices can change them.

[4] Scholars in Governmentality Studies, who follow Foucault and emphasize how discourses make actors responsible for particular parts of their lives, originally introduced the term "responsibilization" (Biebricher 2011; Lemke 2002). Scholars in Vision Assessment have articulated their theoretical indebtedness to this tradition (e.g., Lösch, Heil, and Schneider 2017).

limited by the ability of actors to selectively adopt particular responsibilities at the expense of others. To this end, actors employ a particular form of visionary practice to which we will refer as *responsibility boundary-work.*

Responsibility Boundary-Work

Boundary-work between science and non-science is widely studied in STS (Burri 2008; Epstein 2011; Jacob 2005; Kasperowski 2021) and beyond (Mikes 2011; Mollinga 2010; Zietsma and Lawrence 2010). Gieryn (1983; 1995) introduced the concept of boundary-work as a reaction to the "demarcation problem" of science from non-science. Discarding a purely theoretical solution, Gieryn argued that "demarcation" is a historical achievement. He understood science "not as inherent or possibly unique, but as part of ideological efforts *by scientists* to distinguish their work and its products from non-scientific intellectual activities" (1983: 781–782, author's emphasis). Gieryn defined such boundary-work as "[scientists'] attribution of selected characteristics to the institution of science (i.e., to its practitioners, methods, stock of knowledge, values and work organization) for purposes of constructing a social boundary that distinguishes some intellectual activities as 'non-science'" (1983: 782).

Some scholars have made a distinction between boundary-work at the "external borders of science as a whole" and "internal boundary-work" between or within different scientific disciplines (Burri 2008: 36, see also Amsterdamska 2005; Ashmore et al. 2005), or between emerging and established scientific sub-fields (Vuolanto 2015). Wainwright et al. (2006) took up Gieryn's concept and developed it further into "ethical boundary-work" to account for ethical issues in biomedical research. Ethical boundary-work integrates ethics, an activity previously considered non-scientific, into the image of science to increase its legitimacy, instead of expelling the non-scientific from science. Hobson-West (2012) used the concept of ethical boundary-work to discuss the use of animals in scientific experiments, considering the human-animal boundary drawn in the justification of such experiments.

Our analysis, although inspired by this work, does not concentrate on what counts as "ethical" research; instead, we focus on the creation or reform of responsibilities in a broader sense, namely as an ascribed relationship between a subject, for example, an individual or a collective, and some object, such as another individual or a task (Stahl et al. 2019), in relation to future visions. Gieryn (1983: 792) acknowledges that boundary-work can "exempt members from responsibility for consequences of their work by putting the blame on scapegoats from outside." However, no further conceptual refinements have been made to make boundary-work suitable to study the attributions of responsibility through visions. Therefore, we introduce the concept of "responsibility boundary-work." Responsibility boundary-work is not concerned with the demarcation of science, but with the limits of responsibilizations that actors find acceptable. We define responsibility boundary-work as the visionary practice[5] by which actors, when strategically conferring and deferring responsibilities in selectively articulating visions of the future, create a social boundary between "acceptable" and "unacceptable" forms of responsibilization. In depicting a responsibility as "necessary" or "inevitable," a vision can create this responsibility, whereas another vision, by evoking other, incompatible responsibilities, can deflect such a responsibilization. To specify how responsibility boundary-work operates, we analyze the visionary practices in a concrete case: NeuroSys.

Case-Study on Visions of Neuromorphic Computing in NeuroSys

In 2022, NeuroSys received funding from the German Federal Ministry of Education and Research (*Bundesministerium für Bildung und Forschung,* abbreviated as BMBF) within the Clusters4Future scheme.[6] The first working phase lasted until the end of 2024 but may be prolonged until 2031 upon positive evaluation by the BMBF. Within the Cluster, RWTH Aachen University, the *Forschungszentrum Jülich*, and the non-profit research company AMO GmbH collaborate with companies working in the semiconductor industry and AI software development, as well as with regional actors, such as the city of Aachen and *Zukunftsagentur Rheinisches Revier*, an agency facilitating the structural change of the Rhenish region. This multi-stakeholder collaboration promises to study, develop, and commercialize neuromorphic computing hardware and corresponding software for AI applications. Neuromorphic computing hardware comprises a computer chip architecture that emulates the neural network of the human brain. This chip architecture is expected to be higher-performant and more energy-efficient than conventional computer hardware, which is commonly used for training AI models. Neuromorphic software and hardware are particularly useful for AI on mobile edge-computing devices, like sensors and smart watches, that process data locally. NeuroSys develops such applications for autonomous driving, personalized healthcare, smart cities, the Internet of Things, and digitalization.

The different visions of NeuroSys play out against the background of global issues of sustainability, geopolitics and AI development, and the region-specific challenge of structural change. Semiconductors generally affect sustainability *directly* because their production involves high levels of energy and freshwater consumption, as well as the use of hazardous chemicals and critical minerals (Belton 2021; Mehta and Prakash 2023). Furthermore, the training of modern AI models consumes large quantities of electricity, which is why more energy-efficient hardware is discussed as a means to mitigate corresponding environmental impacts (Strubell et al. 2020; Verdeccia et al. 2023). At the same time, the NeuroSys cluster may have an *indirect* effect on sustainability as well. Semiconductors enable many other technologies needed for the European Green Deal—including electric vehicles, windmills,

[5] Strictly speaking, we are talking about "*visionary* responsibility boundary-work." Throughout the article, we will only use "responsibility boundary-work" for the sake of readability.

[6] For more detailed information about the NeuroSys cluster, see Smolka et al. (2024).

and smart grids—and this has rendered the capacity to design and produce chips in Europe crucial for sustainability aims (European Commission 2019; Gailhofer et al. 2019). As a result, NeuroSys has been trying to find collaborators with whom to develop "green AI" (Schwartz et al. 2020) or "AI for sustainability" (Van Wynsberghe 2021). While current AI development in the cluster focuses on medical applications, video segmentation, and language processing, future applications could advance climate change adaptation, help companies and public administrations to produce less waste and optimize resource consumption (Rohit et al. 2020).

With regard to geopolitics, the growing interest of policymakers in Europe, the US, and elsewhere is driven by the worsening relationship between the People's Republic of China and the US (Bown 2020; Sacks 2023; Varas and Varadarajan 2020). The contested status of Taiwan is a central issue in the conflict. Since the island state is the world's leading producer of advanced microelectronics, the growing tensions have disruptive potential for the global economy (ibid.). In the case of armed conflict in the Strait of Taiwan, this could cause a lasting disruption of value chains (Gordon, Mullen, and Sacks 2023; Sacks 2023). To increase resilience toward supply chain vulnerabilities and to strengthen Europe's position in the semiconductor industry, the European Commission introduced the European Chips Act. The Act will provide public investment in European chip design and production, while a large part of the investment will be channeled to the development of energy-efficient microprocessors for AI applications (ibid.), such as those researched in NeuroSys.

Third, NeuroSys relates to the project of creating ethical AI (Coeckelbergh 2021). Ethical concerns include the transparency and reliability of AI. As a generic term, AI is often used to refer to the more technical concepts of machine learning (algorithms making predictions based on training data) and deep learning (a subset of machine learning that analyze training data and make predictions similar to how the human brain draws conclusions). Since it is difficult to understand, even for experts, how deep learning algorithms transform input into output, concerns about concealed biases in decision-making have arisen. If algorithms pick up biases from training data, these biases may be reproduced and exacerbate existing patterns of discrimination in decision-making in which AI is involved (Benjamin 2019; Chun 2021; Hu 2020; Murdoch 2021). Moreover, data protection and privacy concerns stem from big data requirements of training AI models in cases where these models rely on personal data and infer sensitive information. To address such ethical concerns, the European Commission (2021: 1) introduced a regulatory framework for "trustworthy AI" that supports non-discrimination and protects privacy. NeuroSys follows this European agenda by including in the transdisciplinary cluster ethicists who co-develop AI applications with software engineers. Moreover, the development of energy-efficient neuromorphic hardware promises to foster data security and privacy because it can be used in mobile edge-computing devices. Such devices process data locally rather than sending them to cloud services of foreign companies, to whose operations European regulation may not apply.

The challenges of AI-related sustainability, geopolitics, and ethics are complemented by a fourth, region-specific issue: structural change. Structural change refers to the reorganization of the Aachen region and the regional economic model after the phasing-out of lignite mining, which has been a central source of wealth for the region for many decades (Roth, Kropp, and Sujata 2020). Some stakeholders hope that NeuroSys can make a contribution to structural change, for example by creating employment opportunities and attracting investment or talent. It remains contested, however, in what ways NeuroSys should and can position itself in relation to the global challenges of sustainability, ethical AI, and geopolitics, and how this affects its potential to make a contribution to structural change. In part for this reason, the evolution of the cluster and its impacts on the issues mentioned are still largely imaginary at the time of writing. NeuroSys is therefore a fruitful empirical case-study to examine how visions as socio-epistemic practices responsibilize actors for certain goals, e.g., sustainability or economic success. Our case-study also highlights the role played by such visions in a research and innovation project that contributes to and, to different degrees, preordains social transformation processes.

Multi-method Approach to Vision Assessment

For this case-study (Flyvbjerg 2022), we adopted a multi-method approach to Vision Assessment that combines interviews with participant observation and document analysis. These methods are part of the broader methodological toolkit of Vision Assessment (Schneider et al. 2021: 4). We conducted semi-structured interviews between August 2022 and May 2023 with researchers, business representatives, and regional stakeholders who are either members of the NeuroSys cluster or members of the external advisory board, complemented by some specifically selected interviewees who have shown interest to join the cluster in the future. Drawing on a purposive sampling strategy, we recruited twenty-nine interviewees representing different career levels, disciplines, and forms of expertise. In hour-long interviews, we asked about actors' understanding of innovation and neuromorphic computing, the goals they would like the cluster to achieve, and the perceived obstacles and adopted strategies to overcome these obstacles. The second author conducted twenty-six interviews and was responsible for transcribing three interviews, whereas the first author conducted three interviews and took care of the remaining transcriptions. Interviews were conducted in German and quotes were translated by the authors, except for those from one interview, which was conducted in English.[7]

In addition to the interviews, we have conducted participant observation at online and offline events. We attended conferences and workshops on neuromorphic computing and AI, as well as NeuroSys-organized seminars and meetings. At these events, we paid particular attention to how visions were articulated in public talks, visually portrayed in presentations and conference posters, and how attendees spoke about the future of NeuroSys as well as neuromorphic computing more broadly in informal conversations. These observations were captured in field-notes. If mentioned during interviews or at events we observed, we consulted publicly available and internal documents, including the project proposals, presentation slides, and

[7] For the sake of privacy protection, we will not indicate whether we used original English formulations or translated particular quotes from our interviews.

various policy documents (e.g., the European Green Deal, the European Chips Act proposal, the European AI Act Proposal, the Germany High-Tech Strategy). While these documents provided background information for our empirical analysis, we did not code or analyze them systematically.

The analysis of our data involved a three-step process. First, we inductively coded interviews and field-notes. Second, we clustered inductive codes, which led to three distinct *satellite visions*—a vision of regional entrepreneurship, a European science vision, a networked-society vison—and a more generic *core vision* from which the other visions originate. This clustering also revealed that these visions differ on the dimensions of space, time, and actor constellation.[8] Third, we deductively applied the four visions and these dimensions to the materials again to sharpen the articulation of these visions. As to our different roles in this analysis, it should be added that the coding was done by the first author and cross-checked by the second author. Finally, the first author drafted the vision narratives and the basic analysis, which were edited by the second author, after which the third author commented on the analysis.

The visions distilled from the interviews and fieldnotes are patterns in the empirical materials rather than exclusive commitments. Neither the core vision nor the satellite visions can be observed in their pure form in the account of a single individual. Moreover, one individual in our sample may be committed to more than one vision. Different visions are invoked in different contexts and with regard to different perceived deficits or questions to motivate, give plausibility or legitimacy to, or enact certain changes that appear necessary or desirable in light of these visions. In the analysis of these visions, we do not differentiate between dominant and marginalized visions. Instead, we seek to account for different points of view and make visible non-dominant alongside more widespread perspectives to make sure that the broad spectrum of normative standpoints that we encountered in the NeuroSys cluster is reflected in the narratives. For this reason, the interview data plays a key role in the analysis. During project presentations and internal meetings, the core vision and, to a lesser extent, the regional entrepreneurship vision were the center of attention, whereas the interview data was more heterogeneous across actor groups. This is why most of the quotes presented later originate from the interviews.

In what follows, we introduce the four visions in the form of brief italicized narratives. These narratives are condensed, synthetic approaches meant to introduce the reader to the visions' core ideas. In the analysis (section on "Responsibility Boundary-Work in NeuroSys"), more empirical material will be provided to give a taste of the language in which the visions are formulated, as well as to elucidate the connection between the visions and the data.

[8] Although derived inductively, we recognize that these dimensions have been, to some extent, preconfigured, as they reflect particular tensions in the project design: the spatial dimension relates to the (contested) priority of making a contribution to structural change through stimulating the local economy. Actor constellations are important as NeuroSys is designed as a multistakeholder project, even though industry-academia collaborations are particularly relevant to raise the required industry funding. In this context, the temporal dimension reflects the different time horizons in which different groups tend to operate.

Empirical Analysis

Visions in NeuroSys

The core vision is often deployed when references are made to "the" NeuroSys vision in public presentations, talks, or internal meetings. This vision strongly resembles the way in which the original funding application describes the future of NeuroSys. While many interviewees agree with this core vision, the agreement could stem from a relative lack of details. Comparable to bare bones, it provides a general structure, which can be fleshed out in different ways. The promissory yet flexible character makes the core vision attractive to use, but its ability to inform how the ascribed beneficial potential of NeuroSys can be realized is limited, resembling the "politics of buzzwords" (Bensaude Vincent 2014). The three satellite visions, by contrast, provide more concrete specifications of the core vision with regard to space, time, and actor constellation. After presenting the visions, we analyze their differences on these key dimensions.

Core Vision

NeuroSys has transformed Aachen into a world-renowned and respected center at the heart of a wider innovation ecosystem of neuromorphic computing. Drawing on the globally acknowledged scientific excellence of regional research institutions and a strong industrial base, highly competitive neuromorphic hardware is regionally produced and globally marketed. Whereas the competition from Taiwan and other countries remains fierce, Aachen-based manufacturers have established themselves as market-leaders in specialized application areas. Hardware made in Aachen has gained a reputation for supporting high standards of ethics in AI applications and semiconductor production, thereby advancing European values without compromising competitiveness. With large corporations playing an active role as manufacturers and customers, the Aachen ecosystem connects economic strength to scientific excellence and highly relevant political and societal aims of technology sovereignty, sustainability, and privacy. By offering high-paying jobs and training the workforce needed, stimulating the regional economy and creating a market for high-quality recreational and cultural activities in the region, the innovation ecosystem of manufacturers and researchers benefits the wider community in the Aachen region. This ecosystem is seen as providing major impetus for handling challenges of structural change successfully.

Regional Entrepreneurship Vision

Through the NeuroSys cluster, the Aachen region has become a vibrant economic center for neuromorphic computing. During the nine-year funding-phase, researchers and regional entrepreneurs have collaborated to align research activities with the needs and business models of established companies (predominantly Mittelstand, *i.e., German mid-tier businesses), and enable the creation of startups, for example, as spin-offs. These companies have therefore managed to take up new findings quickly and integrate them into innovative products and services. Researchers have been able to consider industry standards and market structures in their work. The resulting competitive advantage has attracted talent and investors, while also fostering further, often privately financed research projects in the area of neuromorphic computing. Innovation in neuromorphic computing is commercially successful and timely applicable, which has stimulated the regional economy and has created job opportunities. As a result of the generally business-friendly environment, larger players from the semiconductor industry have been attracted and high value-added chip production has been enabled in the region.*

European Science Vision

NeuroSys and similar research projects have established Aachen as a leading research center for neuromorphic computing, which has made decisive contributions to this emerging research paradigm. As performance increase of microprocessors through miniaturization reached physical and economic limits, researchers searched for fundamentally new ways of thinking about computer chips and identified the neuromorphic computing paradigm as a promising way to continue to improve performance. In the early stages of the project, conditions were more challenging. The progress in computing technology and AI astonished people across the world, while it was also clear that the technological and scientific gap between Europe, on the one hand, and the US and China, on the other hand, had widened. Through projects such as NeuroSys, however, the gap has been narrowed. With a focus on scientific excellence and the qualitative newness of insights and innovation generated by the cluster, the reputation and visibility of the Aachen region has been increased. By establishing and cultivating contacts with other leading institutions, NeuroSys has become an important knot in a much larger network of research institutions preoccupying themselves with neuromorphic hardware in and beyond Europe. The highly skilled workforce, educated in the cluster and fluctuating within its larger European network, is expected to benefit science rather than strictly entrepreneurial developments or applications.

Networked-Society Vision

The Aachen region has become a strong example for how cutting-edge, high-tech research can be coupled and aligned with region-specific and global challenges, resulting in a strong focus on ethics and sustainability. In the course of the public funding phase, researchers have constantly included and collaborated with regional actors (e.g., public and private sector, policymakers, civil society). Through participatory formats, they have worked on better descriptions of region-specific and global challenges and on finding better ways to address them through research and other activities. Goal pluralism (e.g., scientific excellence, economic value, social aims) has been acknowledged and reflected in decision-making. While trade-offs could not always be avoided, the actors have ensured that no single goal dimension *prevailed at the expense of others; actors have sought to aim for constantly generating synergies. The holistic approach of NeuroSys has advanced mutual trust and has cultivated the ability to collaborate across sectors and disciplines, which now proves to be very useful for creating similar synergies in other domains. Responsible sourcing and production, high privacy standards, energy-efficiency, and a wide range of sustainable applications serve as distinctive features of neuromorphic technology from Aachen, and these also set it apart from its competitor*s.

Responsibility Boundary-Work in NeuroSys

The abovementioned visions create a social boundary between acceptable and unacceptable responsibilities, ascribing certain responsibilities to certain actors, while deflecting responsibilities from others. Such responsibility boundary-work operates on the dimensions of space, time, and actor constellation. Strategically expanding or limiting spatial and temporal foci, calling for new forms of actor constellation or insisting on the (perceived) status quo, actors confer and defer responsibilities that are ascribed to them through different visions. In what follows, we analyze differences between visions on these key dimensions and their respective practices of responsibilization. The results are summarized in Table 1.

Space

The notion that some kind of semiconductor production facility—often abbreviated as "fab"—should and will be built in the Aachen region[9] based on, or advanced by, NeuroSys features prominently in the core vision and in the regional entrepreneurship vision: "Of course, it would be a tremendous success if we could motivate one of the big players [e.g., TSMC, GlobalFoundries, Intel] to build a fab here in the region" (Interview with senior researcher 16.08.2022). In the core vision, regional and global dynamics are closely entwined: "[T]he innovation ecosystem is global … I have had talks with Intel and TSMC. But what we want to do, realistically speaking, is Europe-wide" (Interview with cluster coordinator 21.10.22). At the same time, a regional foundation is seen as important: "There are boundary conditions from the Federal Ministry of Education and Research. It [the innovation ecosystem] needs to be regional. But we have done that. The core is regional" (ibid.). Through the regional entrepreneurship vision, scientists are responsibilized for the economic success and competitiveness of regional entrepreneurs: "The application should be in the center: what can I do such that it results in value creation? That's not so easy for a researcher" (Interview with industry association representative 02.11.2022). However, some industry representatives are worried that an overly local focus would be undue: "An ecosystem must also work globally. You know the hyperscalers,

[9] The category of *region* as opposed to, e.g., Europe, is flexible, however. Vivid discussions take place among the project partners whether the "region" should encompass certain neighboring municipalities, be limited to Aachen city, or stretch across the greater area of the Rhenish Lignite Area, which as a whole is affected by structural change.

Table 1 Differences between visions in NeuroSys

Visions	Analytical dimensions			Effect of visionary practices
	Time	Space	Actor constellation	Responsibilization
Core Vision Aachen region as world-renowned and respected center at the heart of a larger innovation ecosystem of neuromorphic computing	Short- and long-term (flexible)	Europe and the region (flexible)	(Assumed) synergies; flexible configurations	Responsibility for (supposedly) synergistic and shared goals
European Science Vision Aachen region as leading research center for neuromorphic computing	Long-term	European focus against the background of global power shifts and changes	Cooperation in an exclusive network of leading research institutions across Europe; competition against enterprises and research institutions in the US and China	Responsibility for a desirable European future in opposition to China and with technological independence from the US
Regional Entrepreneurship Vision Aachen region as vibrant economic center for neuromorphic computing	Short-term	Regional focus (Aachen Region)	Cooperation in regional networks; competition on global markets	Responsibility for commercial success of regional companies (small and medium-sized enterprises and start-ups); market structures and industry standards shape research activities
Networked-Society Vision Coupling and alignment of cutting-edge, high-tech research with region-specific and global challenges	Short- and long-term (coupled)	Glocal (global and local coupled)	Regional and trans-sectoral cooperation; synergies need to be created	Responsibility for regional and global challenges; prominent role of ethics and sustainability

Amazon, Facebook and so on. These are ecosystems, too, which create value for all participants and are not local" (Interview with industry representative 16.10.22).

By contrast, the European science vision stresses that, due to the significant difficulty in making qualitatively new inventions, scientific success can only be achieved in a Europe-wide ecosystem of excellent institutions: "I believe that generally speaking in scientific work, and this applies to any discipline; the ecosystem is not necessarily local or needs to remain local" (ibid.). Spatial requirements for groundbreaking science are infrastructurally optimal conditions, for example, in the form of research facilities in the Aachen region and other European countries. In an informal conversation at a semiconductor conference in Germany, a representative of an international technology company not affiliated with NeuroSys described the idea of establishing Aachen, Leuven in Belgium, and Eindhoven in the Netherlands as a regional triangle bundling expertise in research and high-tech companies such as ASML and Aixtron. Instead of building a "mega-fab" as in Magdeburg, specialized medium-sized fabs in the region could cooperate closely. Furthermore, one could establish in Aachen an outpost of the microelectronics research center IMEC. To many with whom we spoke, the exact location of a chip manufacturing facility was eventually unimportant as long as it will be built in Europe: "Honestly, I really don't care if this fab is in Aachen, in Belgium, in the Netherlands, or in the North of Spain. Or if any other place is better, for whatever reason" (Interview with senior researcher 10.11.2022). In the light of concerns about Europe's relatively weak position in the semiconductor industry and research in comparison to the United States and Asia, the European science vision places the spatial focus on Europe. As one interviewee observed: "If it [neuromorphic computing] could become the main driver of innovation in this domain [the semiconductor industry], this would have appeal beyond the city of Aachen and the region and has the potential to enable change for the whole region" (Interview with civil society representative 10.05.2023). Yet, considering the conflictual past of lignite mining, job creation needs to be balanced against sustainability concerns and other positive societal contributions: "There will be people who say: Yes, without these jobs, without this value creation, we cannot live in the region. Others will say: No, you're destroying the basis of life," due to the energy- and water-intensiveness of semiconductor manufacturing and the use of chemicals harmful to the environment (Interview with municipality representative 25.01.2023). In the networked-society vision, the project should also create region-specific societal benefits beyond economic gains: "This has enormous potential . . . for the region . . . ranging from jobs to positive impact on the region and the continent [Europe] to concrete questions of ecological sustainability" (Interview with civil society representative 10.05.2023).

The difference between the visions in terms of *space* corresponds to the prioritization of publications and new patents in the science vision, as opposed to the creation of regionally marketable products in the entrepreneurship vision. Scientific excellence is emphasized in the former, and economic value in the latter vision. Widening the spatial focus, for instance, by stressing the *European* relevance of NeuroSys and situating it in the *global* power struggle is a strategy through which the actors using the European science vision can deflect local responsibilities, which the entrepreneurship vision is actually trying to create. By contrast, narrowing the spatial focus to the Aachen region, for example, by insisting that research results need to be concrete and applicable for entrepreneurs who are active in the region tries to overcome this resistance. Responsibility boundary-work is achieved through strategically invoking the spatial aspect of the vision to give plausibility to a specific option under conditions of contestation.

Time

In addition to space, *time* is a contested dimension in which the visions differ. Through the European science vision, actors *expand* the temporal focus, stressing that the scientific newness and institution-building require stamina and a long time-horizon: “[T]he longer-term path I find a lot more interesting . . . which is to start from the very beginning and to say: Let’s build up a completely new way of doing AI, different from what we’ve been doing so far” (Interview with senior researcher 02.11.2022). The contramotion in the regional entrepreneurship vision *reduces* the temporal scope and focuses on the nearer future: “The aim is obviously to, in the short- and mid-term, produce results which have a fairly high readiness, which we can bring nearer to local firms, such that an added value for the firm, for the production of today, is created” (Interview with business association representative 02.11.22). The regional entrepreneurship vision insists on timely available innovation, which is aligned with present industry standards and market structures to give the adopting companies a competitive advantage. Accordingly, researchers should, in their daily work, consider questions of market success and technological compatibility: “What does it mean for our customers in different application areas if they really want to adopt this technology? How complicated are the interfaces? What does system integration look like?” (Interview with industry representative 29.09.22).

The networked-society vision focuses on the *connection* between the short and long-term and is thus opposed to the exclusive long-termism of the European science vision, demanding that there must also be a short-term contribution to regional and global challenges, for example, through the creation of well-paying jobs in the region to advance structural change or less resource-intensive chip production to reduce the environmental impact of computing: “Chip production is anything but a resource-saving, environmentally friendly technology. It starts with the materials used and doesn’t end with the chemicals needed for production . . . [H]ere, technological innovation can be helpful” (Interview with senior researcher 10.11.22). What is needed, then, is a “network of partners from different domains, meaning industry, science, society, and then different specialized fields” (Interview with municipality representative 08.11.2022) to ensure that long-term efforts are entwined with short-term impact on the region: “For me, success would mean that we can initiate long-term cooperation . . . and can also create use cases which are for us *as a region, as society in our daily lives* interesting and applicable” (ibid). Technological innovation should be coupled with long-term socio-technical system innovations, such as the circular economy: “In the second and third funding phase, we should include this as a central aspect into NeuroSys: How can semiconductor production become part of a circular economy?” (Interview with senior researcher 10.11.2022). Some members of the NeuroSys cluster argued that science, always in search of publishable results and new research funding, has a shorter time-horizon than the private or public sector. Such results are, as others complemented, the basis for innovative products, which took longer to develop and market, but should not be conflated with long-term oriented impact on the research landscape or society.

In sum, both the regional entrepreneurship vision and the networked-society vision seek to reduce the temporal scope and to responsibilize actors in NeuroSys to take action for the nearer future, creating a counterbalance to the long-termism of the European science vision. However, they do so in different ways: The former focuses on the short-term availability of innovation for the market, whereas the latter pronounces the interconnection of short-term impacts with the more distant future through contributions such as innovation-enabling, resource-saving computing technology. The European science vision, by contrast, evokes a responsibility for long-term efforts, such as achieving a paradigmatic shift in computing or European technology sovereignty.

Actor Constellation

Despite their differences, both the regional entrepreneurship vision and the European science vision stipulate a conventional division of labor between actors from science, public, and private sectors. Actors from the different sectors should cooperate and coordinate their actions, but each sector should focus on its key task: providing favorable conditions for research and entrepreneurial activity (public sector), producing knowledge aligned with industry standards and market structures (research), and turning knowledge into marketable products and services (private sector). *Within* their sector, actors are imagined to compete (e.g., against other universities or foreign businesses), whereas *across* sectors, cooperation is key.

By contrast, both the core vision and the networked-society vision break with this conventional division of labor and the resulting actor constellation. The latter suggests that the established separate evaluation of scientific excellence (e.g., based on the number and quality of publications) and of the economic impact (e.g., through the number of jobs created) is insufficient: “If one has worked in tech for the last couple of years, as I have, it was all about only two topics: scientific progress and economic exploitation. And it’s precisely the defining strength of NeuroSys that we can go beyond this” (Interview with senior researcher 10.11.2022). The success of the cluster should rather be tied to its contribution to global and regional challenges, presupposing a joint effort to get a thorough understanding of their scope and nature, involving coupled contributions by all sectors. A researcher suggests to interrogate, at an early stage of research and development, whether scientific progress and economic exploitation are indeed “helpful to address the crises we currently face or whether these are means to worsen certain crises” (ibid.). Cooperation should be deeper and more rigid, whereas the competitive element features less prominently in this vision. As one interviewee indicated: “I hope we could, next to the technological and economic goals we are pursuing, develop things that are beneficial to society and help us to make progress as a society” (Interview with municipality representative 08.11.2022).

The core vision also breaks with the conventional division of labor, but with a different focus. This vision is not explicit about *how* actors should work together and *who* should be responsible to make sure that, for example, a facility for producing neuromorphic hardware is built, but creates a meta-responsibility to assign these roles and responsibilities. The conventional division of labor is not taken for granted. Instead, the actor constellation is thought to be more fluid and malleable, such that a conventional model, while remaining an option, could be abandoned or outright rejected. As the core vision is not committed to any particular actor constellation, it can be deployed for deflecting responsibility. In the vision statement of NeuroSys, the use of passive voice, impersonal verbs, and the attribution of agency to the NeuroSys cluster as a whole indicate a refusal to pick out specific actors as responsible for bringing about certain changes:

> NeuroSys aims to establish the Aachen region as the world's leading location for research, development and innovation in neuromorphic hardware for AI. To this end, all competencies will be bundled in the region and build up into an innovation ecosystem that is required for the development of future European AI hardware. The long-term vision is to develop a genuinely European path through technological independence in this ethically and economically sensitive area.[10]

In this way, the core vision avoids the creation of new commitments and impedes the reallocation of existing or the invention of new responsibilities. At the same time, it preserves flexibility, as it allows for multiple actor constellations to develop. The networked-society vision, by contrast, claims that the responsibility gap *could* be closed if a more cooperative actor constellation is achieved, and both challenge framings and solution approaches are worked out collaboratively. As one interviewee commented: "We want to have people on board, on a broad basis" (Interview with senior scientist 10.11.2022). Multiple actors, beyond industry, politics, and academia, need to be included into negotiations and planning in NeuroSys:

> We need to see what different interests exist in a societal context, and who is representing these interests in what way . . . [On the one hand, there are] the Industry and Trade Association, the German Federation of Trade Unions, the City Council of Aachen, the City Region of Aachen, the City Region Council, different players in the area of structural change, the phasing-out of lignite mining. … On the other hand, there are critics, for instance, environmental organizations such as BUND, NABU, or regional initiatives. (Interview with civil society representative 10.05.23)

Such actors should be brought together through diverse dialogical formats. In articulating the networked-society vision, some stakeholders with some experience of such formats (e.g., research coordinators, city officials, and structural change

[10] This quotation is derived from the application for the first funding phase of NeuroSys. This vision statement was reiterated at several NeuroSys events, for example, at the kick-off meeting and cluster-wide status seminars.

managers) admit that they entail the risk of being instrumentalized to fabricate public acceptance, for instance, for a chip manufacturing facility. At the same time, there is hope that dialogue can stimulate new forms of collaboration, which would allow for the creation of synergies, which the core vision assumes without pointing out their origins or requirements. Through insisting on the core vision, however, attempts to assign responsibility in the sense of any satellite vision can be deferred, because the core vision sustains the ambiguity that the satellite visions are trying to reduce.

The Politics of Visions

The empirical analysis shows that actors in NeuroSys produce and circulate conflicting visions of the future. As Hausstein and Lösch (2020) argue, such a "clash of visions" indicates a politicized future of societal transformation: visions influence the transformation processes responding to grand challenges, which include sustainability, technology sovereignty and structural change in the case of NeuroSys. Future narratives are used to achieve "promissory legitimacy" (Beckert 2019) for certain agendas. As Hausstein and Lösch (2020: 89–91) continue their argument, visions as formative elements in social transformations should be examined by looking at "power constellations," which can change through "clashes" between visions, that is, when different visionary practices compete for influence. In this sense, struggles over future visions reflect power struggles[11] in the *present*, for example, over which actors should lead the way and who should follow. In the regional entrepreneurship visions, for instance, entrepreneurial goals and business interests, which are only of marginal importance in the European science vision, are given greater weight. In deflecting the attempt to make researchers responsible for entrepreneurial success, the latter vision grants researchers a leading role in shaping future developments, whereas the former does the same for entrepreneurs. The responsibility boundary-work reflects this power struggle. The contestation of visions indicates epistemic uncertainty as well as normative-political contestation, thus calling not only for more research and knowledge, but also for political reflection and deliberation.

Moreover, the contestation of visions reflects disagreement over future social orders attainable through, and supportive of, neuromorphic technology. The regional entrepreneurship vision stipulates a social order close to the perceived status quo in terms of actor constellation and marketable innovation stabilizing this order. Structural change is imagined as a technological transition (from mining area to microelectronics center), which preserves—rather than fundamentally transforms—social order oriented toward economic growth through technological innovation. It bears

[11] We acknowledge that structural boundary conditions, such as the funding scheme, which requires co-funding by industry, could influence or predetermine the course of this power struggle in favor of a business-oriented trajectory. However, due to the lack of formal means to exercise authority within the cluster, actors have enough room for maneuvering to aspire different, competing visions. Therefore, the use of visions as an oft-neglected social force is particularly relevant.

some resemblance to what Pfotenhauer et al. (2023: 11) call a "conservative innovation culture," in which innovation is framed as a means to preserve existing socio-economic orders. By contrast, the networked-society vision challenges the existing social order in two consequential ways. First, it requires substantial adjustment in the division of labor between sectors and disciplines. Second, it aims at further changing society through collaborative action and technology development to better prepare the region to address global and regional challenges. In this sense, the vision can be characterized as advancing "progressive" innovation. In the European science vision, by contrast, the scientific field of computing and related disciplines are supposed to be transformed, but not the social order in the Aachen region. Through the proliferation of microelectronics and applications based on them—AI, most notably—social orders in Europe can be expected to change, but in ways that involve other, more prominent actors (e.g., industry, public sector).

Such makings of future social orders through visions can be interpreted as moments of co-production. What social order is co-produced with science and technology in NeuroSys is, in part, the result of the impact of visions on research and innovation practices in the present. How practices are (not) changed, and what notions of responsibility this (lack of) change reflects, is however not a direct consequence of circulating visions, but of their interplay with actors' responsibility boundary-work. Depending on how actors confer or defer responsibilities, the social orders to which research and innovation practices contribute differ significantly. Power struggles through visions in the present therefore influence and reflect, but do not determine, the co-production of future orders. Tensions between visions reflect conflicts over desirable social orders and power distributions within them, revealing that the visionary practices are socio-political as well as socio-epistemic in nature.

Crucially, responsibility boundary-work influences which circulating visions have a chance of becoming collectively held, winning over institutional support, and be performed in public, thus achieving the status of an STI for an (imagined) community in the Aachen region or the surrounding Rhenish Area. It is too early to give a comprehensive empirical description of this ongoing, still accelerating process of contestation and re-stabilization. The concept of responsibility-boundary work can guide such analyses to understand the process better, stressing actor-specific motives that influence the adoption or rejection, or the alteration or abandonment, of visions in the process of STI-making. To account for the interconnectedness of both phenomena reflected in conflicts over visions—power struggles in the present and struggles over future social orders attainable through and supportive of science and technology—we suggest the term *politics of visions*. It sums up the notion that visionary practices are not neutral, but committed to particular, often idiosyncratic notions of the "right" social order and the power distribution within it.

The *politics of visions* are related to Beckert's "politics of expectations" (2016: 11), which refer to attempts by economic actors to influence expectations in such a way that the distributive outcomes align with the actors' expectations. Such attempts can be successful because even if expectations are "fictional," as they motivate decisions (e.g., investment decisions) with real consequences (2016: 10 et seqq.). The *politics of visions* are similar insofar as this concept, too, captures the translation of a hypothetical entity—a vision, similar to an expectation—into a form of materialized reality. However, the *politics of visions* accentuate more strongly the role of scientific knowledge and technology in shaping social orders: depending on how visions impact practices of knowledge production and innovation, for instance, by creating specific responsibilities, different social orders are co-produced. The concept therefore complements the focus on economic activity prevailing in Beckert's analysis with a sensibility for co-productionist dynamics.

Conclusion

In this article, we asked how actors facilitate and limit *responsibilization* through future visions, which we analyzed as socio-epistemic practices. Using the NeuroSys cluster as a case-study, we found that actors engage in what we called *responsibility boundary-work*. Through conferral and deferral of responsibilities, they create a social boundary between acceptable and unacceptable responsibilization. Responsibility boundary-work operates in the dimensions of envisioned time space, and actor constellation. By strategically shifting foci in these dimensions, actors can advance but also limit responsibilization, thus marking off the limits of responsibilization. Finally, we discussed the relationship between visions, changing power constellation, and the co-production of social order, after which we proposed *politics of visions* as a useful term when it comes to accounting for these entwined phenomena.

Although we focus on responsibility boundary-work as a *visionary* practice, the concept could also be useful for praxeographic studies of value negotiations (Mol 2002), for rhetorical studies of science communication or policy documents (Gilbert and Mulkay 1985), or for the genre of controversy studies (Pinch 2015). In these STS-inspired research areas, the concept of responsibility boundary-work could be used to analyze the practical and rhetorical strategies through which actors attribute and demarcate responsibilities in the enactment of specific values or knowledge claims. Further research could investigate how responsibility boundary-work shapes and is shaped by field structures (Bourdieu 1998; Fligstein and McAdam 2011), regimes of valuation (Fochler et al. 2016), or established STIs (Jasanoff and Kim 2015). The latter could be of critical importance if research seeks to make the analytic potential of STIs fruitful for analyses of processes of change or social transformation, focusing on the practices through which actors produce changes of or a transition between STIs held by certain communities.

Along these lines, this article makes a second contribution to the literature on STIs: analyzing how responsibility boundary-work unfolds over time helps to better understand the evolution of a "vanguard vision" (Hilgartner 2015) into an STI, that is, through which discriminatory practices actors shape processes of STI-making. The concept helps to pay attention to the practices through which new visions are made compatible with existing imaginaries, or through which actors seek to alter or replace an existing STI. Considering responsibility boundary-work and the politics of visions may also benefit the growing literature trying to make use of the STI concept to analyze social transformations (Beck et al. 2021; Kim 2018; Sepehr and Felt 2023).

Finally, we contribute to the growing literature on Vision Assessment, and in particular, to the efforts to make this literature fruitful for analyzing and advancing "responsibility" in research and innovation. The analyzed *politics of visions* cast doubt on the visionary planning optimism put forward by Transformative Vision Assessment, that is, the belief that visionary practices can be used to deliberately steer transformation in particular directions, e.g., toward sustainable development (Frey and Schneider 2022) or R(R)I (Schneider et al. 2021). Our empirical analysis demonstrates how actors can, through responsibility boundary-work, limit or resist the attempts to "transform" their practices or assign them a different position in actor constellations. Accordingly, we suggest that governance approaches committed to integrate societal values in innovation and research should attend to responsibility boundary-work and the politics of visions. Complementing such approaches with an analysis of visionary practices may help acknowledge the limits of steering societal transformations in response to grand challenges. In this context, the questions if and how responsibility boundary-work can be modulated, and which specific responsibilities of TA scholars, practitioners of responsible innovation, or other engagement researchers emerge from such an (im)possibility, seem relevant in particular to Vision Assessment, ethics of innovation (Sand 2018), and responsible innovation governance (Stemerding et al. 2019). In NeuroSys, we plan to implement a dynamic learning agenda (van Mierlo et al. 2010; van Veen et al. 2014) and analyze its potential to modulate responsibility boundary-work.

Visions cannot exercise their otherwise considerable influence on processes of sociotechnical transformation on their own account, but depend on the "right" responsibility boundary-work that allows for the "right" kind of responsibilization, thus enabling new forms of collaboration and the formation of alliances through which challenges can be addressed and desirable change initiated. However, the politics of visions—power struggles between actors in the present and disagreements over desirable future social orders reflected in conflicting visions—complicate this alliance-building. Therefore, responsibility boundary-work can also severely limit the transformative potential of visions and stifle reform processes. As TA and R(R)I are permanently confronted with the need to anticipate, evaluate, and guide (sociotechnical) change, the creation of new actor constellations and the closely associated changes of responsibilities, it is essential to develop conceptual and methodological means to analyze and guide the impact of responsibility boundary-work on these processes.

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Author Contribution Philipp Neudert contributed to the empirical data collection, analyzed the data, created the conceptual framework, wrote the first draft of the research article and edited subsequent versions. Mareike Smolka designed the study, supervised and carried out major parts of the empirical data collection, supervised and supported the data analysis, and edited multiple versions of the article. Stefan Böschen designed the study, supervised the data analysis, and commented on multiple versions of the article.

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Declarations

Conflict of interest The authors have no competing interests to declare that are relevant to the content of this article.

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