THESIS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY

Too Enabling to Fail:
Tracing Sub-Politics Across Tensions Between Nanosafety and Innovation

NICHOLAS SURBER

Division of Science, Technology and Society
Department of Technology Management and Economics

CHALMERS UNIVERSITY OF TECHNOLOGY

Gothenburg, Sweden 2025

Too Enabling to Fail:
Tracing Sub-politics Across Tensions Between Nanosafety and Innovation

NICHOLAS SURBER

Acknowledgements, dedications, and similar personal statements in this thesis, reflect the author's own views.

DOI: 10.17196/9789181032277
ISBN: 978-91-8103-227-7

Doktorsavhandlingar vid Chalmers tekniska högskola
Ny serie nr 5685
ISSN 0346-718X

Division of Science, Technology and Society
Department of Technology Management and Economics
Chalmers University of Technology
SE-412 96 Gothenburg
Sweden
Telephone + 46 (0)31-772 1000

Cover photo: A series of values, principles, and miscellaneous issues and concerns applicable to innovation processes and sorted as either ideal, essential, or non-essential.

Typeset in Goudy Old Style and Sabon Next LT

Printed by Chalmers Digitaltryck
Gothenburg, Sweden 2025

Too Enabling to Fail:
Tracing Sub-politics Across Tensions Between Nanosafety and Innovation

NICHOLAS SURBER

Division of Science, Technology and Society

Department of Technology Management and Economics

Chalmers University of Technology

ABSTRACT

Previous research has emphasized a need for new governance of science and technology because of the perceived failures of risk regulation in the context of emerging technologies in technoscientific capitalism. This need has coincided with nanotechnology, positioned to enable a future safer and more sustainable economy. New governance combines regulation with soft regulatory innovations that lack legal force, such as codes of conduct, standardization bodies, and public engagements. These arrangements render previously 'non-political' institutions, especially science and industry, as political.

This thesis pursues how these arrangements can be understood through sub-politics, a framework introduced by Ulrich Beck. Nanotechnology in Europe is the empirical setting for the governance horizon of pursuing nanosafety towards innovation, generally conceived as responsible development and increasingly as safe innovation. This thesis argues that pursuing this horizon must involve mediating its political tensions, rather than filling a governance gap with toolkits.

These tensions are elaborated through three empirical studies that deploy stakeholder analysis, argument mapping and expert interviews. Five appended papers are presented using Beck's framework of sub-polities, sub-policies, and sub-politics. They highlight various sub-politics in European nanotechnology governance that reflexively coalesce values of safety and responsibility with progress and innovation.

Tracing these sub-politics offer three signal contributions. First is to propose a hybrid organization of the promissory advocate, an amalgam of intermediary, advocacy and promissory organizations. Second is the paradox of a multiplication of uncertainty amongst proliferating tools of soft regulation. Third is the tendency to promissory legitimation crisis, when confronted by promissory credibility and reflexive scientization. Together, it is argued that the political-economic commitment of nanosafety through innovation renders nanotechnology Too Enabling to Fail.

KEYWORDS: Risk sociology, economic sociology, sub-politics, nanotechnology, risk governance, reflexivity, soft regulation, political economy of research and innovation, technoscientific capitalism, nanosafety

Too Enabling to Fail:

Tracing Sub-politics Across Tensions of Nanosafety and Innovation

NICHOLAS SURBER
Avdelning vetenskap, teknologi, och samhälle

Institutionen för teknikens ekonomi och organisation

Chalmers tekniska högskola

SAMMANFATTNING

Tidigare forskning har lyft fram behovet av nya styrformer för vetenskaplig och teknisk utveckling, som ett svar på upplevda brister i riskreglering av framväxande teknologier som faller under den ekonomiska ordning som kallats ”technoscientific capitalism.” Detta behov har sammanfallit med utvecklingen av nanoteknologi, vilket positioneras som en potentiell möjliggörare av en mer hållbar ekonomi. De nya styrformerna kombinerar lagstiftning med icke-rättsliga initiativ, som uppförandekoder, standardiseringsorgan och samverkan med allmänheten. Dessa initiativ leder till att tidigare opolitiska institutioner, särskilt inom vetenskap och industri, blir politiska.

Denna avhandling undersöker hur dessa arrangemang kan förstås genom ramverket ”sub-politics”, vilket framtagits av Ulrich Beck. I en europeisk kontext är nanoteknologi kopplat till förväntningar kring ansvarsfull innovation och sedermera säker innovation. Denna avhandling argumenterar att det för att driva denna utveckling krävs det att de politiska spänningarna hanteras genom förhandling, snarare än att försöka fylla de regleringsmässiga luckorna med diverse verktyg.

Dessa spänningar förklaras med hjälp av tre empiriska studier som använder sig av intressentanalys, argumentationsanalys och expertintervjuer. Avhandlingen inkluderar fem artiklar som använder sig av Becks ramverk för ”sub-polities”, ”sub-policies” och ”sub-politics.” De undersöker ”sub-politics” inom den europeiska styrningen av nanoteknologi som förenar säkerhet och ansvar med framsteg och innovation.

Utifrån dessa studier av ”sub-politics” framhävs de tre viktigaste bidragen. Det första är förslaget av en hybridorganisation av typen ”promissary advocate”, en blandning av en förmedlande, prognosskapande och intresseorganisation. Det andra är konceptualiseringen av ”multiplication of uncertainty” i anslutning till det växande utbudet av frivilliga initiativ. Det tredje är en tendens till en ”promissory legitimation crisis” i vilken tilliten till dessa löften kombineras med det reflexiva vetenskapliggörandet. Tillsammans argumenterar dessa bidrag för att nämnda de politisk-ekonomiska åtaganden kring nanosäkerhet genom innovation innebär att nanoteknologi betraktas som ”too enabling to fail.”

For Bonnie,

my editor extraordinaire who saw politics
everywhere

LIST OF PUBLICATIONS

This thesis is based on the work contained in the following appended papers, referred to by Roman numerals in the cover paper text. Further publication history and contributions, applying the Contributor Role Taxonomy (CRediT), are subsequently detailed below.

I. Palmås, Karl, and Nicholas Surber. 2022. "Legitimation Crisis in Contemporary Technoscientific Capitalism." *Journal of Cultural Economy* 15 (3): 373–79. https://doi.org/10/gp535d.

II. Shanley, Danielle, Joshua B. Cohen, Nicholas Surber, and Shauna Stack. 2022. "Looking beyond the 'Horizon' of RRI: Moving from Discomforts to Commitments as Early Career Researchers." *Journal of Responsible Innovation* 9 (1): 124–32. https://doi.org/10/gpxj7r.

III. Surber, Nicholas. 2025. "Who's Who and Where: Responsible and Economic Development in the Evolving European Nano-race." Under review at *Journal of Nanoparticle Research* (supplemental material included).

IV. Surber, Nicholas, Rickard Arvidsson, Karl De Fine Licht, and Karl Palmås. 2023. "Implicit Values in the Recent Carbon Nanotube Debate." *NanoEthics* 17 (2): 10. https://doi.org/10/gsc44n.

V. Palmås, Karl, and Nicholas Surber. 2025. "Regulatory fictions as coordination devices: How professionals anticipate future bans on chemicals." Under review at *Socio-Economic Review*.

PAPER I

Author contribution
Contributing author

Conceptualization, methodology, writing–review and editing

Previous versions
Virtual presentation at 4S/EASST Conference, 18 August 2020, as "Sculpting Responsibility through Legitimation: Placing Nano in Wider Sociological Narratives"

Virtual presentation at Nordic STS Conference, 20 May 2021, as "Legitimacy and time in technoscientific capitalism"

PAPER II

Author contribution
Contributing author

Conceptualization, methodology, writing–original draft, review and editing

PAPER III

Author contribution
Sole and corresponding author

Conceptualization, methodology, investigation, data curation, validation, formal analysis, project administration, visualization, writing–original draft, review and editing

PAPER IV

Author contribution
First and corresponding author

Conceptualization, investigation, methodology, data curation, project administration, validation, visualization, writing–original draft, review and editing

Previous versions
Presentation at internal *Mistra Environmental Nanosafety* Program Meeting, Stockholm, Sweden, 24 November 2021, as "Tacit values in the recent carbon nanotube debate"

Presentation at Chalmers STS Division Seminar Series, 1 December 2021

PAPER V

Author contribution
Contributing author

Conceptualization, investigation, methodology, data curation, project administration, validation, writing– review and editing

Previous versions
Presentation at 4S Conference, Honolulu, Hawai'i, USA, 10 November 2023, as "From Responsible Innovation to Safe and Sustainable by Design? Ethics governance at a Swedish nanotechnology hub"

Presentation at 4S Conference, Honolulu, Hawai'i, USA, 10 November 2023, as "The temporal politics of regulatory fictions: On the prediction and promotion of future Legislation"

Virtual presentation at Anticipation Conference Online, 4 November 2022, as "Between consultancy and advocacy: The politics of anticipating future regulation"

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

BAuA	German Federal Institute for Occupational Safety and Health
BSE	Bovine Spongiform Encephalopathy (mad cow disease)
CalSAFER	Safer Consumer Products Information Management System
CBEN	Center for Biological and Environmental Nanotechnology (Rice University, US)
Cefic	European Chemical Industry Council
CLP	Classification, labelling and packaging (of mixtures and substances) legislation
ChemSec	International Chemicals Secretariat
CSR	Corporate social responsibility
DG RTD	Directorate-General of Research and Innovation (EC), formerly Research and Technology Development
EC	European Commission
ECHA	European Chemicals Agency
ECR	Early career researcher
EHS	Environment, health and safety
ELS	Ethical, legal, and social sciences
EU	European Union
EUON	European Union Observatory on Nanomaterials
FP	Framework program
GMO	Genetically modified organism
ISO	International Standardization Organization
nano-EHS	Nanotechnology environmental health and safety
NEST	New and emerging science and technology
NGO	Non-governmental organization
NNI	National Nanotechnology Initiative (US)
OECD	Organization for Economic Co-operation and Development
OHS	Occupational health and safety
PERI	Political economy of research and innovation
REACH	Registration, Evaluation and Authorization of Chemicals (legislation)
RI	Responsible innovation
RMIT	Royal Melbourne Institute of Technology
RRI	Responsible Research and Innovation
SbD	Safe (or safety) by Design
SIN	Substitute-It-Now
SME	Small and medium enterprise
SSBD	Safe and Sustainable by Design

STS	Science and technology studies
SUBSPORTplus	Substitution Support Portal
SVHC	Substances of Very High Concern
VCI	German Chemical Industry Association

ACKNOWLEDGEMENTS

There are many to acknowledge and express my gratitude, between (1) colleagues, (2) friends, and (3) family, who have together helped sustain me to foster this culminating doctoral dissertation.

First, I still admit to not understanding why my supervision team, with **Karl Palmås** as lead, supported by **Rickard Arvidsson**, and examiner **Sverker Molander,** preceded by **Per Lundin**, decided to hire a forest ranger (technically, recreation technician) from his reclusive retreat in the Rocky Mountains. As any doctoral candidate learns, it takes a lot of encouragement and persistence on the part of their team to proceed along the doctoral journey. In my case, this is a journey of almost six years.

Now I will mention a few work colleagues. I would like to thank everyone at the division of **Science, Technology and Society** with the TME department at Chalmers. I am also grateful for the guest post at the **Environmental Systems Analysis** division and the interdisciplinary interest in safety and sustainability. To those I saw on a more quotidian basis, I am grateful for the company **of Kai Lo Andersson, Angelica Wågström, Parissa Mokhtabad Amrei, Maria Ciotti and Natalia Seiti**, in sharing office space and meandering conversation over the years. On that note, I will emphasize the co-authors at Chalmers, **Karl Palmås, Rickard Arvidsson** and **Karl de Fine Licht.**

In the final months, weeks and days, I have been lucky to benefit from some diligent editing work on this thesis. A preliminary draft of the thesis was discussed at length at a final seminar, directed by **Harald Throne-Holst**, which has been instrumental in producing a clearer text. I would like to also highlight some last minute help from **Julia Johansson** and **Aron Ambrosiani.**

The cover paper you are about to read, or peruse, directly began as a licentiate level (midway) thesis, defended on 20 April 2023. I have learned much from that early defense seminar, guided by the discussant, **Lea Fuenfschilling,** at Lund University.

A critical boost arrived in the form of a delayed Research Proposal seminar, on 30 October 2020. I simply cannot thank my junior discussant **Barbara Hedeler** and senior discussant **Sverker** (above) enough times for their critical and generative efforts at contextualizing and elucidating a fledgling version of the project.

This project was only made possible by the principal investigators and of Mistra, the Swedish foundation for strategic environmental research, in the creation of **Mistra Environmental Nanosafety**. I am grateful for their belief that the more-than-technical aspects of nanomaterials in society deserve greater recognition and, hence, elaboration. I reminisce fondly on the combined sense of discovery and spirit of camaraderie during our years together, despite the obstacles of international collaboration over the Corona pandemic. This was especially true within the miscellaneous environs of "Work Package 4", with **Karl** and **Rickard,** and the stalwarts **Steffen Foss Hansen, Lauge Peter Westergaard Clausen** and **Maria Bille Nielsen** from the Technical University of Denmark. I also acknowledge the encouragement, support, and brilliant gardens from **Lennart Gisselsson,** also at Lund University.

I further wish to thank **Tommy Cedervall and his research group**, connected with the Mistra program, based at the chemistry center at Lund University. They have kindly hosted me during most of these PhD years and slowly revealed some of their ways in the nanoecotoxicology of plastic(s) breakdown. A special acknowledgement goes out to all the **biochemistry PhD students** there, including **Egle Kelpsiene,** for demonstrating the similarities and differences between the sciences and a certain hope for the future of interdisciplinarity.

The third and final guest research visit has been to the Institute for Technoscience and Society at York University, in Toronto, Canada in the autumn of 2023. A few quiet weeks in a new city were apparently the key to drafting what will follow as Paper III. I thank both **Kean Birch** and **Kelly Bergstrom** for quickly facilitating the visit and helping develop that paper.

I am also grateful for the process and product of producing a discussion paper, Paper II, during the pandemic. The fellow 'RRI-a-holics' involved—**Danielle Shanley**, **Joshua B. Cohen,** and **Shauna Stack**–might not have written the RRI manifesto as planned, but perhaps we have said something interesting about the state of RRI and the novel idea of collaborating as young researchers across Europe. We have collectively learned that one can indeed combine article writing and the spirit of afterwork with just enough Belgian beer and institutional Zoom subscriptions.

From the GoNano winter school for doctoral candidates, held precariously at the start of February 2020, I wish to thank the candor and willingness of the fellow doctoral candidate participants to teach a socio-environmental scholar some basics in doing nanotechnology. I will mention the assistance of **Craig Richmond** and **Daan Schuurbiers**, who have laid down a path for successor scholars in social studies of nanotechnologies.

The planning and execution of a creative writing course—during the coronavirus pandemic, no less–has furthermore been significant in shaping my writing perspective(s), with the original spark from **Kjell Vowles** and **Malin Nordvall.** I must also thank **Charlotta Kronblad** for many fascinating conversations about our manuscripts and our collective quest for explorative writing styles.

There are of course too many teachers from university experiences prior to Chalmers, so I will digress with two honorable mentions. I am grateful for learning more about eco-Marxism and the "thermodynamics of imperialism" from **Alf Hornborg** at the Human Ecology group with Lund University and for having the nerve to take a graduate course in the history of water management in California at the University of California, Berkeley, overseen by none other than **Richard D. Norgaard** and the Energy and Resources Group there.

At this point, I would like to also thank the **erstwhile and unnamed mentors** who have intersected with the project. Their support, even if just in cultivating interviews and a research network, has been instrumental in imagining a world where this work can indeed contribute.

Second, I must insist in there being a special place for those friends willing to stand by and with a doctoral candidate. I *do* know that there is a world 'out-there' beyond nanosafety, innovation and reflexivity, but they are central in reminding me to experience it. In no particular order (not quite true), I am grateful to **Ludwig** and **Ronja, Ingrid, Melina, Manon, Emelie, Kristoffer,** and **Tatiana.**

Third, there are multiple families spread over the Atlantic, who have together put me out on loan. Genetically speaking, I refer to the **Surber family** (mostly in California and Idaho), the **Paione family** (mostly in North Carolina). To **Alex** and **Mark,** you know who you are. I would be remiss to ignore the **Moore family** and **Sturges family** (both mostly in Idaho). Moreover, I express my gratitude for having a 'home away from home' in the pastoral German Kreis of Westerwald in the **Massow** and **Tönnishoff families**. Thank you all for telling me the mountains can wait. They beckon with the spring thaw.

– Gothenburg, Sweden
5 May 2025

To be sure, risk cannot be banned from modern life, but what we can and indeed should achieve is the development of new institutional arrangements that can better cope with the risks we are presently facing; not with the idea in mind that we might be able to regain full control, but much more with the idea in mind that we have to find ways to deal democratically with the ambivalences of modern life and decide democratically which risks we want to take.

Ulrich Beck (1997, 13-14)

ONE/ **INTRODUCTION**

In January of 2020, I received an impatient email instructing me to submit a one-slide, two-minute elevator pitch regarding my research project. The occasion was an upcoming "Winter School" hosted at the Royal Melbourne Institute of Technology satellite offices (RMIT, Australia) in Barcelona (not Australia) and situated within a European research program called GoNano.[1] Apparently, our introductions to the cohort were preordained by roundtables of "elevator pitches" to be rated by other junior researchers (i.e. students.) My slide found a few crafty buzzwords about the political economy of research and innovation and mapping technological and funding developments in the world of nanotechnology. And without further hullabaloo, off I went by train—so many trains—to Barcelona for the first week of February.

I soon learned that this pitch would be merely one of about thirty. On Tuesday, the School began with a blitzkrieg of colorful nanoscience pitches—apart from my dreary black and white text. The competition was energized by strict timekeeping, a rigid presentation order and the occasional filming and photography by promotional staff. All students were then told to mark their preferred pitch with a Post-it note on the respective A3 slide printout spread across the two conference rooms. This was no idle task. Starting Wednesday, diverse groups were formed by the coordinator-researchers (part of the broader GoNano team) after tallying the Post-its. Each group was led by a superlative presenter, refashioned as "problem leader", which instigated a process to "co-create" a solution to the problem leader's research problem that would mobilize the week.

The solution, without fail, was a nano-sized innovation. After the blitzkrieg, the setup was to engage in a mock co-creation process with the problem leader's nano-project as exemplar. In our case, the problem leader was working on nano-filtration, and the problem was to re-imagine this project after a stylized societal intervention.

Simultaneously, each group together learned the practices through which co-creations animate the larger zeitgeist of "Responsible Research and Innovation" (RRI), the ethical framework of the moment by the European Commission (EC.) Students, to their credit, read the GoNano reports, watched YouTube recaps of the program's real-life co-creations, and remained attuned to the various lectures, debates, and plenaries from the

[1] Please see the old project (and still active) website here: https://gonano-project.eu/

GoNano team, stretched across the entire four-day affair. In parallel, the initial innovations were to be rendered responsible—responsibilized even—to meet the core learning outcomes and pass the course.

In between the cautionary tales and practical advice, each group returned to their stations to progress through the four step, mock co-creation tutorial. In step one, we discussed each group member's disciplinary perspective on our problem, to re-contextualize the problem at hand. Next, we ranked the potential preferences for this product from the perspective of a future consumer. Step three entailed a three-dimensional prototype to incorporate the multidisciplinarity (step one) and consumer preferences (step two) to conjure up a better, or at least responsibilized, solution. We lastly drew up a storyboard sequence, the task of step four, to illustrate one future use scenario as the epitome of our co-creation.

Not that much had changed for the initial nano-filter from Tuesday. The nano-filter remained, with the added benefits of a piezoelectric potential for self-cleaning. The traditional, albeit inefficient, membrane technology had been replaced by nanofibers, which were subsequently replaced by carbon nanotubes in the co-creation.

These improvements were ultimately two or even threefold. First, the problem leader began the week with a nanofiber-based filter as a solution to limitations of water filtration. Second, after the group identified issues with efficiency and cost-effectiveness, the fibers became carbon nanotubes (owing to the piezoelectric breakthrough.) Third, even I, the resident 'social scientist', was made to understand the key concepts and rationale for the alterations. The team was ecstatic at the improved design, despite my expressed concern in substituting for carbon nanotubes.

With this solution, our group succeeded in the presentation and passed the course. The problem was 'led' and improvised over the course modules to supposedly become a prototype of RRI. Case closed, problem solved, diploma received—and all on time.

Alas, what was the problem here in Barcelona? Our nano-filter can be problematized in two ways. One, the nano-filter was one of many problems for research and innovation carried through the glass doors and into the RMIT satellite. Can it work? Can the nano-filter simply filter? Two, this functionally improved nano-filter was also a responsibilized solution to a societal problem. For us, we reframed this solution/problem as no less than clean water, in how to better ensure a clean water supply for a global population that often goes without. The problem was thus furnishing a responsibilized solution by students disciplined in a rationale of functional improvement.

Gap or tension?

This thesis is not primarily about nanotechnology and responsibility, nor *responsibilized solutions.*[2] This thesis is also not about GoNano. More than anything, this thesis stems from the functional improvement is substituting nanofibers for carbon nanotubes as an anecdote for the wider governance of nanotechnology. This thesis hence intends to relate nanosafety and innovation as a problem of governance. Fundamentally, nanotechnology governance can be pursued through two metaphors: as a gap or tension.

The *governance gap* approach posits that while nanotechnology development (like any other new, emerging technology) proceeds at speed, the controlling governance apparatus is slower to respond. This creates the metaphorical gap. In the case of nanotechnology, the problem has generally been framed as a need for 'risk governance' in a context of novelty, one where previous apparatuses cannot be readily applied as before (see Renn and Roco 2006, 1.) For others, the governance gap is essentially a regulatory problem: the pacing problem, where "[...] our traditional government oversight systems are mired in stagnation, ossification and bureaucratic inertia, and are seriously and increasingly lagging behind the new technologies accelerating into the future" (Marchant 2011, 199.) As a gap, the problem is both regarding novel (nano)technology and the governance apparatus.

Nanotechnology governance has embodied a dueling ambivalence, in alternately *constraining* risks and *enabling* innovation, that suggests the *tension* metaphor. Traditionally, regulation has been viewed as *ex post* efforts to manage and mitigate risks. Nanotechnology, however, arrived "[...] in debates about the modernisation of policy systems implying a transition from constraining to enabling types of policy or regulation (i.e. from ''sticks'' to ''carrots'')" (Renn and Roco 2006, 5.) The governance gap is to be filled—not from more *status quo* governance—but from an enabling, *ex ante* logic that trundles from risk governance to innovation governance.

In enabling innovation, the "policy system" is being remade for commercial applications and enabling technologies in this future-oriented political economy of research and innovation. Over twenty years ago, this new regime saw

> nanotechnology as the jewel in the crown of current publicly supported science. Nanotechnology is a nearly perfect fit for what both companies and

[2] In this thesis, italics will be additionally used as stylized emphasis. Boldface is deployed to aid the reader in referring to other sections for clarification.

> the government expect from science. [...] the development of the field is less stymied by the challenges it presents to traditional modes of doing science – e.g., transdisciplinarity, focus towards applications, ties to proprietary industrial research, blurring of science and engineering" (Johnson 2004, 10.)

Nanotechnology governance entails support in promoting and public funding for these applications. All this funding is moreover an investment in the economic growth "engine" of nanotechnology underwriting a future research and innovation fueled *and enabled* economy (2004, 11.) Enabling technology is therefore about promoting certain futures over others.

This presents as a logic of 'Too Enabling to Fail.' Simply put, enabling technologies are new and novel technologies which are promised to be economically essential for the society of tomorrow. Nanotechnology symbolizes the dual promise of enabling technologies–one where innovation currently enables (promises) and shall eventually constitute (deliver) a key source of economic growth. Nanotechnologies belong to a class of enabling technologies (see Svendsen et al. 2020) that are perhaps not yet 'too big to fail', but their high promises and public investments make them 'Too Enabling to Fail.'

'Responsibility' and 'safety' represent two common enabling discourses that have been positioned to fill the governance gap. Nanotechnology governance, at the outset, was defined through 'responsible development.' Given the risks posed, there was a need "[...] to assess [...] what ethical, social, health, environmental, safety and regulatory implications these developments may have", according to the milestone UK report (Royal Society and Royal Academy of Engineering 2004, 87.) This responsible development (see also European Commission 2004), often associated with the subsequent EC Code of Conduct (2008a), was later extended from nanotechnology to the research and innovation process writ large under the aegis of RRI.[3] This later era of RRI dissemination was in the background at the Winter School. Responsible development has also been adapted into proactive design solutions towards safety. This began first with 'Safety by Design' (SbD) (e.g. Kelty 2009), which is currently being established as an EC Recommendation (2022) under 'Safe and Sustainable by Design' (SSbD) and as innovation governance in the 'Safe (and Sustainable) Innovation Approach' (Groenewold et al. 2024; OECD 2020; Soeteman-Hernandez et al. 2019.)

[3] Responsibility discourses, exemplified through nanotechnology, have been framed in Europe under various concepts. Three fundamental examples are 'responsible development', 'responsible innovation' (RI), and 'Responsible Research and Innovation' (RRI.) RI and RRI will be referred together as RRI in this thesis for simplicity and to highlight the role of policy-making in their prominence. It is cognizant of the different academic and policy-making settings and ongoing discussions on responsibility terminology (Randles, Tancoigne, and Joly 2022.)

Thesis aim and structure

These frameworks have contributed to the framing of developing governance to enable nanotechnology, as one part of the problematization of how to govern nanotechnology. Instead of investigating the governance gap, this thesis proceeds from the tensions of nanotechnology governance outlined between constraining risks and enabling innovation. For earlier scholars of the governance tension, for instance in Rodríguez's study of European Union (EU) policies, "[...] the different political bodies in the EU share the assumption that the industrial development of nanotechnology within the context of a competitive, knowledge-based, global economy is compatible with environmental and health safety" (2018, 16.) Åm's dissertation (2011a), building on two case studies on the emergence of German and UK nanotechnology governance, proposes a secondary tension, of a politics of politicization, that underpins a "logic of pre-emption" embodied in "hegemonic" responsible development. More than balancing a tension, "[...] nanotechnology governance is aligned in the goal to pre-empt conflict, that is, to avoid a politicisation of nanotechnology" (2011a, 235.)

This thesis seeks to extend the analytical focus of a tension in policy-making and the political system to broader areas of governance outside these boundaries. It aims to understand the tension between enabling nanosafety and innovation in the European governance landscape.

The structure of the thesis is as follows. Next, in Section 2, the **research context** will detail the emergence of a tension between nanosafety (research) and innovation. Readers already familiar with this context can skip this. The theory of sub-politics is presented in the **theoretical framework** of Section 3, which culminates in the staging of three research questions (see page 25.) **Section 4 on previous research** then outlines how sub-politics has been considered in the literature on nanotechnology governance. Section 5 recounts the **methods** enrolled in the thesis for both theoretical papers and empirical studies, concluding with some reflections on reflexivity. Thereafter, the underlying five papers are introduced in Section 6, as the **summary of appended papers** that presents their individual contributions. The three research questions are answered inductively through a primary **analysis** of the papers in Section 7. Findings from previous research are later traced, in Section 8, onto the appended papers, with the aid of the theoretical framework, to generate a secondary **discussion** underscoring three signal contributions. The thesis **concludes** in Section 9 with a brief recapitulation of the thesis and three future avenues of departure.

TWO/ **RESEARCH CONTEXT**

This section contextualizes the thesis topic of nanosafety and innovation through three cardinal steps. Step one is the emergence of nanotechnology, in parallel strands of technological development, science policy and rising environmental concern. Step two is to introduce the risk society thesis, Ulrich Beck's contemporary sociology, that articulates conceptualizations of risk as a generalized side-effect, alongside the simultaneous pursuit of safety. Step three is the ethos of reflexivity in the case of nanotechnology that manifests as nanosafety, and to a lesser extent, as nanophobia.

Historicizing nanotechnology: an imbroglio of fiction, science and technology

What does it mean to speak of nanotechnology? At a first glance, the answer might seem to be technology at a (very) small scale. However, the origins of the term can be viewed broadly as both science and technology *fiction* and *fact.* The literary scholar Colin Milburn explains nanotechnology as a concept introduced by speculative science fiction in the early twentieth century (2010, 24–28, 46–49.) In other words, nanotechnology did not emerge historically from any empirical discovery of science or technology, but rather as a fictional imaginary of the distant future. Nanotechnology hence is an imbroglio of fiction and facts that is orientated to a fundamentally uncertain future.

There are at least three origin stories to nanotechnology that offer a contradictory framing as plausible and future-oriented, but not entirely fictional. Two seminal "apostles" (cf. Amato 1991) have contributed to generating imaginaries of nanotechnology: the physicist Richard Feynman and early nanotechnologist K. Eric Drexler. One is seen through Feynman's vision (1960) of miniaturization in "There's Plenty of Room at the Bottom"—a speech given at California Institute of Technology in the US. The second is exhibited in the work of Drexler, most notably in *Engines of Creation*, which imagines a future of molecular assembly (1986), in an early declaration of nanotechnology as scientific concept (cf. K. E. Drexler 2004.) In between, the first reference of "nano-technology" in the scientific literature—another origin story—is evidenced by Taniguchi (1974.)

Any definition of nanotechnology typically begins with the refrain to size: technology at a small scale. Size-based boundaries highlight its interdisciplinarity, with combinations of traditional disciplines working together both to study and produce nanoscale phenomena. Precise operational definitions are many (see Boholm and Arvidsson 2016;

cf. Maynard 2011), due in part to the many disciplines nanotechnology coordinates. To start, one consensus definition is that

> nanoscale science, engineering, and technology, known in brief as 'nanotechnology', is the understanding and control of matter at 'dimensions of roughly 1 to 100 nanometers, where unique phenomena enable novel applications (qtd. in Roco 2023, 1; cf. Barben et al. 2008, 980; cf. Hansen et al. 2007, 2.)

Nanotechnology depends on the size of the "nanoscale" that then depends on the opaque boundary from bulk to "unique phenomena."

Nanotechnology can be contextualized to both antecedents and succeeding fields of science and technology. In the history of science, nanoscience proceeds as a successor to the materials science of the mid-twentieth century (Bensaude-Vincent and Hessenbruch 2004; Eisler 2013.) Smart nanomaterials (Gottardo et al. 2021), advanced materials, and advanced nanomaterials are today developing, with nanotechnology as just one component (Hristozov et al. 2024, 2.) Nanotechnology, looking backward, has often been seen as the next emerging technology wave after biotechnology (Seifert and Fautz 2021.) Across research in science and technology studies (STS), the phenomenon is generally framed in the hybridized form of technoscience: nano-technoscience (e.g. Arnaldi, Lorenzet, and Russo 2009; Pellizzoni 2012.)

This thesis will refer to nanotechnology as the specific term signaling the greater project of nanoscale science and technology that is oriented around these future visions and is framed and governed in part by policy.

Nanotechnology as science policy

The settlement of nanotechnology has signified an evolution in the "political economy of science" (Tyfield 2017) towards innovation, through its shifting "institutional arrangements" (Macq, Tancoigne, and Strasser 2020, 2–3.) The US and Europe are two important geopolitical regions, with separate arrangements.

In the US, nanotechnology is coordinated by and through the National Nanotechnology Initiative (NNI), representing over 30 national agencies (Roco 2023, 1). The NNI itself signaled a consolidation around the terminology, nanotechnology, and its policy arrangement (see Roco 2011; Gallo 2009.) [4] Since then, funded projects have been

[4] The NNI has been profiled at various times over its development by, amongst others, Mihail C. Roco, the longstanding nanotechnology enthusiast at the National Science Foundation in the US (Roco 2011,

promoted "[...] to fill major gaps in fundamental knowledge of matter and to pursue the novel and economic applications anticipated for nanotechnology" (Roco 2011, 2.) This NNI strategy has channeled approximately $40 billion in direct public investment alone, from 2001 to 23; its rapid success has catalyzed over 80 countries (by 2005) to copy these initiatives (Roco 2023, 3.)

Germany and other EU countries are amongst these followers (Roco 2023, 3.) However, at the EU level, the EC does not mirror the NNI and instead relies upon multiple funding mechanisms. In general, and for nanotechnology, the predominant funding mechanisms are organized as framework programs (FPs), administered primarily through the Directorate-General of Research and Innovation (DG RTD.) This system originated in 1984 with Framework Program 1. Funding has increased over time: notably after the 2008 financial crisis with research and innovation positioned as central EU policy objectives (Macq, Tancoigne, and Strasser 2020, 4, 10–13), as shown in "EUropeanization" of research infrastructure (Cramer and Rüffin 2025.) The two most recent programs are the ongoing Horizon Europe (2021-2027) and the preceding Horizon 2020 (2014-2020.) Europe, and the EU in particular, represent the spatial focus in this thesis.

Nanomaterials, nanoparticles, and nano-enabled products

Specific nanotechnologies involve a manipulation of nanoscale objects, generally as nanoparticles and nanomaterials. Nanoparticles are "relevantly measured" in the nanoscale in all three dimensions, whereas nanomaterials refer to one or two dimensions (Boholm and Arvidsson 2016, 35–36.) Researchers and innovators develop nanoparticles, nanomaterials, et cetera, which are ultimately aggregated into nano-enabled products for consumers in a nascent marketplace, comparable to chemical substances (Hong, Som, and Nowack 2023, 1–2.) This marketplace, and environmental implications, can be partly understood through production and consumption statistics.

Nanoparticles and nanomaterials are in fact understood as both naturally occurring and engineered. First, they occur naturally in the environment through natural processes like weathering and have been used unknowingly throughout history (Erhardt 2003.) Second, engineered nanomaterials refer to intentional manufacturing at the nanoscale (Hansen et al. 2007, 2–4.) Nanoscience, therefore, is a result of new research capacities,

427–28.) The NNI was announced in January 2000 during a speech by President Bill Clinton at the California Institute of Technology. Previous funding and organizational efforts focused on smaller research areas and differing arrangements than nanotechnology, for instance, "ultra-precision engineering."

also known as “instrumentalities” (de Solla Price 1984, 3), to explore a concurrent world of very small, nanoscale phenomena. Nanomaterials will be used in this thesis to refer to technological artifacts engineered at the nanoscale.

Since the boom in economic interest for nanomaterials in the 2000s, products have been tracked by inventories, as “[...] an important resource and bellwether of the pervasiveness of nanotechnology in society” (Vance et al. 2015, 1769.) In the US, an early forerunner was the Nanotechnology Consumer Products Inventory (CPI), with a relatively low estimate of 1,814 products, circa 2013. Higher estimates come from the newer and European focused Nanodatabase, based in Denmark (Hansen et al. 2016.) The Nanodatabase has surpassed 5,000 entries; their own analysis concludes that applications are clustered around the main categories “health and fitness”, “home and garden”, and “automotive” (Hansen, Hansen, and Nielsen 2020.) In terms of constituent nanomaterials, silver, followed by titanium, titanium dioxide and carbon (for example, carbon black and carbon nanotubes) are the most prolific in the Nanodatabase.

Studies on the production of nanomaterials, in addition to the product inventories, provide another statistical viewpoint. Compared to general figures (e.g. Cefic 2025) of millions of metric tons for chemical substances, nanomaterials are reported in no more than the thousands of tons (European Chemicals Agency 2022.) [5] A prominent survey of industry representatives by Piccinno and colleagues (2012, 4–7) reports on global production in terms of tons per year, claiming that titanium dioxide is most common (10,000 tons), with additional metal oxides and carbon nanotubes also prominent (each in the range of 100 to 1,000 tons.) Less prevalent in Europe are silver, quantum dots and fullerenes (less than 10 tons.) However, the numbers for silicon dioxide vary from negligible (less than 1 ton) to extreme (more than 100,000 tons.) This uncertainty–explained by the lack of agreement in demarcating between bulk and nanoscale silicon dioxide–points to the problem in delimiting nano from bulk materials.

Another method to generate production statistics is through modelling flows of nanomaterial life cycles. One such modelling study, from Keller and Lazareva (2013) reveal major nanomaterial production ranges (listed in decreasing order) as various metal oxides, iron, nanoclays, carbon nanotubes, and finally, far smaller amounts of

[5] Specifically, this is 217 million tons of chemicals produced in the EU for 2023 (Eurostat 2024), with total sales reported from Cefic (the European Chemical Industry Council) at 655 billion Euro for 2024 (Cefic 2025, 3.) In an estimate for 2020, EUON (the European Union Observatory on Nanomaterials) lists 140 thousand tons and 5.2 billion Euro in sales (European Chemicals Agency 2022, 12.)

copper and silver. This study proceeds to map nanomaterial use and release, which is concentrated in Asia, then trailed by Europe and North America (2013, 66–68.)

The risk society and reflexivity

The case of nanotechnology helps to show the rise of commercialization and innovation as a central policy concern. Why is innovation such a priority? The answer can be seen to lie in two signal shifts towards reflexivity in Western society,(1) political economy and (2) risk.

In the political economy, the welfare state model comes into crisis from the 1970s, challenging the generalized industrial society. Amongst other challenges, this involved a crisis of economic competition. The crisis has been evaluated by many, influentially through the *Legitimation Crisis* typology of Jürgen Habermas (1975), and eventually adapts into diagnoses of a "post-industrial society" by Daniel Bell (1973) and *The Postmodern Condition* from Jean-François Lyotard (1984.) These diagnoses collectively assert a shift from a material goods, or commodities, economy to an innovation economy oriented around knowledge production.

Analyzing goods and innovation, alone, miss an essential dynamic in the new political economy: the condition of risk. The sociologist Ulrich Beck responds to these diagnoses by postulating the *Risk Society* theory. He declares in 1986 that we are "living on the volcano of civilization", constantly on the verge of eruption (1992, 17,76.) [6] For Beck (1992, 21), the conceptualization of risk is paramount. His specific understanding starts at,

> *Risk* may be defined as a *systematic way of dealing with hazards and insecurities induced and introduced by modernization itself*. Risks, as opposed to older dangers, are consequences which relate to the threatening force of modernization and to its globalization of doubt. They are *politically reflexive* [original emphasis.]

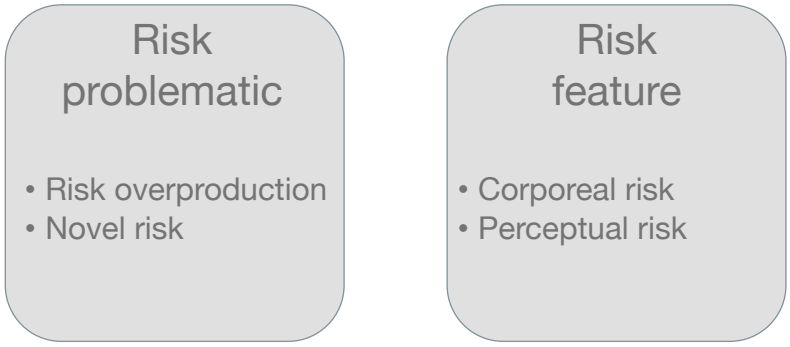
The risk society is only partly an industrial society. The alleviation of material scarcity—modernization in other words—loses priority to a risk management of "dealing with hazards." Risks today are thus threats of modernization, "the threatening force", whereas risks yesterday are marginalized as "older dangers" to be solved by accumulation, namely, more material wealth. Risk stands apart from previous eras of danger, in that modernization, for society, maintains its status as solution to dangers and becomes

[6] The original title was *Risikogesellschaft: Auf dem Weg in eine andere Moderne,* in 1986, which was translated from the German for the 1992 version. The full English language title is *Risk Society: Towards a New Modernity*.

problematic through risk. Modernization (effect) continues to address danger while also being confronted with itself (side-effect.) [7]

Risk can be classified by two sets of dual aspects, summarized below in **Figure 1**. On risk, there are two problematics: risk overproduction and novelty. Industrial risk is not especially new, as characteristic to modernity, but its accelerating production over time becomes harder to contain or control. This condition is defined as risk overproduction (Beck 1992, 21.) Novel risk, however, refers to the production of new risk forms which require new knowledge to manage, as much as possible. On risk features, inhabitants reside alongside the corporeal and perceptual components of risk. Corporeal risk expresses the direct manifestation of hazard through vectors of exposure. Perceptual risk signals the present emotive experience to a future possibility, such as fear, anxiety or angst, as a reflexive response to potential corporeal risk. This latter aspect speaks to the harm of not knowing if, when, or how Beck's "volcano of civilization" will erupt—of living with uncertainty, rather than manageable risk.

Figure 1. Risk typology in risk society



Scientization, progress and politics in techno-tragedies

The risk society co-exists with economic innovation, yet the increasingly scientific and technological origin of risk imply both overproduction and novelty. In Beck's vocabulary, scientization is an essential process that refers to knowledge production as a central response to both danger and risk. In modernity, risk is effectively scientized, that is, translated from an environmental problem into science.

[7] This thesis centers around Beck's work that stems from *Risk Society* to understand reflexivity in nanotechnology development. The succeeding *Reflexive Modernization* compilation continues this work, but with a broader focus on modernity. Thus, it is comparatively outside the analytical scope.

Scientization is the direct institutional response of science to risk. Beck (1992, 158) clarifies the transformation of scientization in modernity in that,

> Scientific civilization has entered a stage in which it no longer merely scientizes nature, people and society, but increasingly itself, its own products, effects and mistakes. Science is no longer concerned with 'liberation' from pre-existing dependencies, but with the definition and distribution of errors and risks which are produced by itself [original emphasis.]

"Scientific civilization" now confronts the consequences of primary and reflexive scientization. This is, yet again, a manifestation of the problem/solution chain. In the primary stage, problems of "nature, people and society" are solved by scientization. Now, however, science attempts to concurrently solve its very own solutions of the (increasingly recent) past. Reflexive scientization is the problematization of solutions, if not also products of problem/solution chains. The 'solution' of innovation is, in essence, imbued with risk.

This scientization response alludes to a *recursive* loop of inflating risk. Science and technology function as a deflationary release to primary scientization. The recursive tendency is legitimized due to the alternately end value and promise of progress through innovation. Progress, as a totem of modernity, is linked to a modern and capitalist economy and embodied in the logic of economic growth. To be explicit, this is *economic* progress. Furthermore, progress in an increasingly technological and scientific society—comprised of innovation as the economic engine (see Johnson 2004) and risk as the exhaust—is thoroughly *techno-scientific* and *techno-economic*. Problems are tolerated as the side-effect price of solutions, or put differently, the cost of techno-economic progress (Beck 1992, 45, 200–203.) Beck's metaphor is direct: "risks belong to progress as much as a bow-wave belongs to a speeding ship."

Two technological controversies of the late twentieth century, amongst other examples, have opened up progress to the political system. These were nuclear power and genetically modified organisms and crops (GMOs). For nuclear power (Beck 1992, 60, 177–78), novel risk manifested in the shape of radioactive fallout and its consequences, exemplified by radioactive bioaccumulation and outright reactor meltdown (in the 1980s UK fallout of Chernobyl, see Wynne 1992.) GMOs highlight a later set of novel risks in the application of genetic biotechnologies to agriculture and food. Similar concerns to nuclear power surrounded GMOs in the expert framings of risk and a culture of scientization in policy institutions, fostering "public alienation" (Wynne 2001.)

Nuclear power and GMOs are therefore early indicators of the politicization of technology development, a situation endemic of techno-tragedies. These two instances challenged the monolithic trajectory of techno-economic progress, documented as "expert cultures of risk" in Wynne's critique (2001.) They can be characterized as techno-tragedies to the degree that politicization led to illegitimacy in a context of previously unchallenged expertise. Techno-tragedies provide a plausible pattern in the possibility of *political*, as opposed to *technological*, failure. This pattern is illustrated through a legitimacy deficit from the (wider) lay public in support of science and technology.

Nanophobia and nanosafety in the risk society

The risk society, demonstrated below in the case of nanotechnology, intuits at least two responses of reflexivity. These are (1) nanophobia by the lay public and (2) the field of nanosafety research.

The framing of techno-tragedies later manifests in an expert discourse surrounding nanophobia (Rip 2006, 10–12.) Nanophobia can be defined as the expected lack of acceptance of nanotechnology by the lay public. In terms of the risk society, nanophobia captures the earlier feature of perceptual risk and its consequences. This possibility of nanophobia arose around the turn of the millennium, for example with the angst in Bill Joy's notable reflection, "Why The Future Doesn't Need Us" (2000.) Without extant nanotechnology to draw upon, its inception in the science fiction fantasies of nanotechnologies run amok (Milburn 2010, 41–46) were rhetorically available. Amongst them are the scenarios of "gray goo" from the nanotechnology apostle Drexler (1986, 146–47), where (to paraphrase) nanobots eventually devour the planet.

The apocalyptic and speculative scenarios, notably in the novel *Prey* (Crichton 2003), filled the imaginary gap of nanotechnology for lay publics. This very perception by experts, according to the nanotechnology scholar Arie Rip, can promote action as nanophobia-phobia, with

> [...] a general presumption that publics are passive and susceptible to fearful interpretations—here, after reading a science fiction novel. Specifically, scientists and technologists (and other promoters of nanotechnology) are prone to project nanophobia, and this projection can become a phobia in itself, a nanophobia-phobia (2006, 11.)

In this context, and in the constant imbroglio of nanotechnology, a recurrent theme is the need to separate fact from fiction. This can mean a neutralization of fiction, perceived as fearful or negative affect (Bowman, Hodge, and Binks 2007.) Hence affect,

as a perceptual risk to the acceptance and legitimacy of nanotechnology, should be carefully managed to promote public acceptance. Experts, however, are granted a presumptively supportive and factual, scientific rationality (cf. Wynne 2001.) This logic has moreover been termed "'the scientists thinks and the public feels'" (Cook, Pieri, and Robbins 2004.) [8]

Twenty years later, engineered nanomaterials constitute part of the material flow of society and are thus actual, corporeal risks. Nanotechnology, as expected, delivers on the promise of techno-economic progress driving modernization. This is the endpoint in the maximization of (desirable) goods. Yet these economic goods co-exist with the undesirable attributes of risk. Nanotechnology comes to realize the reflexive logic of both maximization of goods, and minimization of bads. Whereas Beck seeks to identify this reflexivity (1992, 55), nanotechnology in particular marks a collapsing temporal dynamic, compared to the techno-tragedies of nuclear power and GMOs. Nano-enabled products are marketed coincidentally, if not even in *anticipation of* nano-enabled risks, with negligible latency between good (effect) and risk (side-effect). Previously latent side-effects become simultaneous in the case of nanomaterials.

True to form, a new field of research emerged to address the potential implications of corporeal risks from nanomaterials (instigated especially by Colvin 2003.) [9] This subsequent turn to risk has changed the analytical lens to the demonstrable properties of nanomaterials rather than the above nanophobia. Two reports, again from the early 2000s, generated lasting momentum: (1) "The Big Down", from a Canadian NGO, calling for a moratorium to nanotechnology research (ETC Group 2003) and (2) *Nanoscience and Nanotechnologies: Opportunities and Uncertainties* in the UK, concluding on the necessity of risk research on implications (Royal Society and Royal Academy of Engineering 2004; cf. Nielsen et al. 2023, 1–2.) In short, it is not just increased risks from nanotechnology–Beck's risk overproduction. The challenge lies also in qualitatively novel risks implied by the "colonization of the nanoscale" (in a critique by Miller and

[8] Regarding nanophobia-phobia, Rip (2006, 3–5) examines the "wow-to-yuck trajectory" as a folk theory from *inter alia* Vicki Colvin, that seeks to explain the lay public perception to emerging technologies, especially nanotechnology. The folk theory proposes that public perception must inevitably move from 'wow' or initial enthusiasm to 'yuck' or subsequent disappointment. Regardless, experts must find strategies to promote public acceptance of this inevitable technology development on a "fickle" public. In this lesson the counterpoint to avoid is the techno-tragedy of GMOs, offering many analogic suggestions for policy-making (e.g. Sandler and Kay 2006) under the aegis of "getting it right the first time" (Walsh et al. 2008). See also (Kulinowski 2004; McCarthy and Kelty 2010.)

[9] This research focus has been generally categorized as nano-EHS, or environmental, health and safety aspects of nanotechnologies. It can be suggested that the fields of nanosafety and nanotechnology risk governance descend from this specific period. See (Dunphy Guzmán, Taylor, and Banfield 2006) for an overview of risk implications research at the NNI.

Wickson 2015, 2), where "unique phenomena enable novel applications" as per the key definition of the nanoscale.

This interdisciplinary field is called nanosafety. The anticipated outcome from the (reflexive) scientization of nanotechnology is found in the reasoning of safety. Safety and risk, for Beck, is an antithetical relation, akin with wealth to poverty (1992, 47–49.) This understanding confronts earlier scientization with axiology: "the place of the value system of the 'unequal' society is taken by the value system of the 'unsafe' society." The safe society is the aspirational and axiological endpoint for the risk society. Rather than latently study the risks of nanomaterials through the established constellation of risk regulation, that is, risk assessment and management (e.g. Klaine et al. 2008), nanosafety is striking for its discursive aim to design and govern nanotechnology proactively—safely (van Hove and Wickson 2017, 3–5) and thus reflexively.

THREE/ **THEORETICAL FRAMEWORK**

Using a broad sociological approach, this section details the theoretical framework of sub-politics, which is a crucial component in Ulrich Beck's theory of politics. Sub-politics will later be applied to examine the tensions of nanosafety and innovation. To do this, the framework elaborates a conceptualization of politics. This begins first through the preeminent sociologist Max Weber and the 'iron cage' idiom, and second through the contemporary transformations of Beck and the risk society. Beck's central pillars of the sub-politics framework, sub-polity, sub-policy, and sub-politics, are then introduced, supplemented by dimensions of sub-politicization and sub-politicking. Theoretical interventions to expand sub-politics after Beck are subsequently displayed as four significant strands. Sub-politics is ultimately distilled into a series of three research questions (see page 25) that will address the thesis corresponding to the three pillars.

Politics after the iron cage

Ulrich Beck departs from the presiding Weberian perspective of politics to articulate his theories of sub-politics and reflexive politics. The Weberian perspective has been represented through the 'iron cage' idiom (e.g. Holzer and Sørensen 2003, 1–2.) The iron cage refers to a bureaucratic "[...] cage [that] must be regarded as a construction, a self-description of a political system that claims to have successfully monopolized the means of doing politics" (2003, 17.)

The political system, instead, can be understood corresponding to an ephemeral "temporal layer" of constantly evolving politics (Palonen 2003, 14.) Palonen (2003) introduces a conceptualization of Weberian politics, expanding from 'politics' to a linked vocabulary of policy, polity, politicization and politicking.[10] This furthermore contains two fundamental qualities of (spatial) sphere, "politics-as-sphere", and (temporal) activity, "politics-as-activity" (2003, 2.) In this account, politics operates conceptually as two pairs: policy to politicking and polity to politicization.

First, policy refers to "[...] a direction of activities, to a line, project, plan, program, or doctrine" that is directed to the future (Palonen 2003, 6.) This future projected by policy maintains a certain normative desirability. A second mode of politics is politicking (2003, 8–10.) If policy is performative and the substance of politics, then politicking is

[10] Palonen's paper (2003) seeks to temporalize Weber's approach to politics. Beck's own theorizations (e.g. 2018) refer back to Weber, albeit implicitly.

the performance. Palonen intuits here the classical Aristotelian distinction between *praxis* (internal aims) and *poiesis* (external aims), with these analogs of policy and politicking.

The third mode is the polity. For Palonen (2003, 10–12), the polity is a valid space of political activity that excludes and labels other activities as non-political. Rather than a monolithic polity as the immutable "political system", polities emerge and depart plurally. They are formed in practice as a "complex of polities." In the fourth mode, polities are produced, in contrast to politicking, by antecedent politicizations. Politicization is a process, referred to by Palonen as, "[...] the act of naming something as political, including the controversies surrounding the acceptance of this naming" (2003, 13.) Through a disruption of extant politics, politicization can either invent new politics from a previously non-political phenomenon or be integrated within ongoing politics. Polities can thus be minimally opened up by politicization, or in the maximal case, wholly constituted by them (2003, 14–15.)

Beck reviews the "political science" understanding of politics similarly, through three pillars of polity, policy and politics, to preface his own political outlook. Specifically, he defines them (1997b, 103) as,

> first, it inquires into the institutional constitution of the political community with which society organizes itself (the *polity),* second, into the substance of political programmes for shaping social circumstances (*policy*), and third into the process of political conflict over power sharing and power positions (*politics*) [original emphasis.]

The polity here represents the generic political system, as a community organized through institutions. Outcomes of this organization deliver policy with social effects. Put differently, as per Palonen, the polity is the sphere of politics, whereas policy and politics demarcate politics as activity. Beck ignores the two earlier process elements of politicking and politicization in emphasizing an iron cage polity and policy, such that politics alone signifies a process involving political agents.

Sub-politics and the reinvention of politics

In the risk society, politics is transformed in the dual sense of sphere and activity. Politics in this epoch is classified into three institutional forms, as either spheres of non-politics, politics, or most significantly, *sub-politics*. Beck (1992, 183–235) prefers the term sub-politics, describing a dialectic of partial politicization of non-political institutions (e.g. science and technology, industry). This is also coupled with depoliticization of the presiding political system, for instance, the decline in electoral participation. There is an

emphasis on process sub-politics, especially sub-politicization, alluded to in both its genesis from the chapter "Opening Up the Political" that concludes *Risk Society* (1992, 183) and in a later article "Ecology and the Disintegration of Institutional Power" (1997a.) [11] These earlier writings are further conceptualized into Beck's political treatise *The Reinvention of Politics* (1997b.)

Sub-politics is housed within extant institutional spheres. For Beck (1997a, 99), sub-politics captures, "[…] a category transformation with *unchanged* institutions, and with intact power elites that have not been replaced by new ones" [original emphasis], one where the formerly 'political' institutions exchange labels with formerly 'non-political' ones. Sub-politics does not mean new institutions; rather, it denotes increasingly central political activity originating from non-politics.

Regardless of "category transformation", polities are produced through politicization, performed by politicking, and all contributing to the production of policy. Applying sub-politics, one can classify a taxonomy that is divided into process and product dimensions. There is the emergence of *sub*-politicized *sub*-polities—sub-politicizing processes underneath and formally outside of the political system, which nonetheless spawns political effects from sub-polity settings. These *sub*-polities perform *sub*-politicking, as a performative component of general sub-politics, towards the mediation of *sub*-policy goals. This taxonomy of sub-politics is visualized below in **Figure 2**, coupled with definitions in **Table 1**.

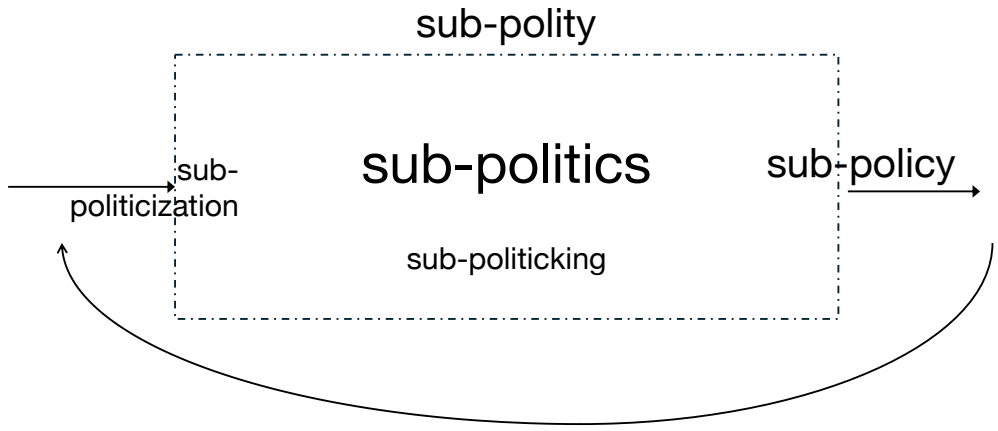


Figure 2. Visualization of sub-politics

[11] This logic of sub-politics can be viewed as "opening up" politicization and "closing down" de-politicization, as per previous research in STS on the turn to public participation in science and technology (Stirling 2008.) Beck's qualifying prefix of *sub-* elucidates the fact that these processes occur increasingly in places outside (or beneath) the formal political system.

Yet who are the political agents of sub-politics? The "category transformation" of sub-politics alludes to two kinds of sub-politician, in an institutional exchange of roles and rising individualization. Formal politicians (*de facto* experts of political system) are decreasingly relevant and joined alongside increasingly relevant technocratic and scientific experts that amount to the next act on the "stage of social design." (Beck 1997b, 103.) Institutional exchange is only the first aspect. These "collective agents" are joined by individuals, acting outside their institutional roles, generally as professionals or citizens undergoing individualization (1997b, 156–59.) Experts might be *prima facie* sub-politicians, however their authority and rationality are challenged by individuals in an increasingly informal struggle for power.

Table 1. Definition of terms in sub-politics

Term	Definition
	Process dimension
Sub-politicization	An 'opening up' or emergence of opportunities for sub-political action
Sub-politics	Generalized political action, as afforded by sub-politicizations, and outside of the formal political system
Sub-politicking	The performance aspect of sub-politics, when sub-political agents knowingly engage in (sub)-politics
	Product dimension
Sub-polity	Organizational settings that function as nodal spaces of sub-politics, subject to ephemeral stabilizations
Sub-policy	Outputs that emerge through, and from, sub-polities and sub-politics

"New political cultures" designate the cultural expression of sub-politics, involving collective agent and individual sub-politicians. Firstly, sub-politics involves a "*generalization* of political action" dispersed amongst individuals beyond the frame of established citizenship (Beck 1992, 195.) Secondly, this generalization is not homogenization, as "[…] politics in newer approaches is now viewed as the collaboration of different agents even *contrary* to formal hierarchies *across* fixed responsibilities" [original emphasis] (1992, 199), ascribing a significant role for professionals in occupations (1997b, 156–60.) Thirdly, the "partial arenas" of sub-politics are either

"extra-institutional" or "institutionally protected." This combines, amongst others, organizations, social movements, non-governmental organizations (NGOs), and protest with more tacit activities in relatively protected institutions of science, technology, industry or business. Sub-politics consequently exist as *underneath* formal politics, while residing within extant institutions, and as *transcendent* in the proliferating individual (and collective) action.

Beck's overarching theory of politics, a convergence of politics-as-sphere and activity, is condensed into **Table 2**. Sub-politics, as characterized above by a transformation of institutional spheres, additionally contains disparate forms of action than formal politics. To explain the transformation of politics-as-activity, Beck returns to "conditions of politicization" to distinguish between pre-existing *simple* and novel *reflexive* politics. This political theory can thus be elaborated as a double transformation (1) from the spheres of formal politics to sub-politics and (2) from the action of simple to reflexive politics—for both institutions of *where* and processes of *how*.

Table 2. Beck's theory of politics

		Politics as activity	
		Simple (rule-directed)	Reflexive (rule-altering)
Politics as sphere	Formal politics	Symbolic politics, economic growth, full employment, technical and social progress	Reactivation or metamorphosis of the state, gutting of politics
	Sub(system) politics	Simple expert rationality, dominance of technocratic, bureaucratic action, private sphere	Reform of rationality, political entrepreneur, occupation as political action

Note: Adapted from (Beck 1997b, 135)

Reflexive politics, or the "politics of politics", captures dynamics of the above Weberian politicization and polity. The implied processes of politics necessitate a reinvocation of politicization, in that "the rhetoric of politicization perhaps requires the simplification of an established polity as a space of stagnating and discriminating practices by neglecting its specific politicizing origins in order to dramatize the break and novelty" (Palonen 2003, 14.) This is analogous to Beck's simple politics "[…] comprehended and operated as a *rule-directed, rule-applying*, but not a rule-changing, much less a rule-inventing, politics; it is a variation in the execution of politics but not a politics of

politics" which demarcates reflexive politics (1997a, 2.) A Beckian theory of politics therefore reflects a convergence of both politics-as-sphere and politics-as-activity–a veritable *Reinvention of Politics.*

Tracing contemporary sub-politics

Numerous studies have proceeded to apply sub-politics after Beck's treatise culminating in 1997.[12] Many of these have foregrounded questions of expertise in technological society, particularly through lenses of STS. [13] [14] Four key theoretical developments are here emphasized in (1) the object of sub-politics, (2) the passive-active continuum, (3) modes of sub-politics and (4) the everyday life of subactivism.

De Vries (2007) proposes an Aristotelian framework for sub-politics, based on a subject-object distinction. Two vital questions in order to study sub-politics, according to de Vries (2007, 4), are identifying "what is the *political* that is implied in subpolitics" and "how to trace subpolitics." In response, the classical concepts of *poiesis* and *praxis* are applied to the emergence of maternal blood screening in the Netherlands. De Vries concludes that studies of sub-politics should be less centered around the *poiesis* of political subjects, and instead the *praxis* of political objects (2007, 26.) Praxis reinforces the importance of polity, rather than processes of politicization and politicking, and the complex of sub-polities that contain political objects. Sub-political action is, however, a matter of actors with sub-political roles.

Studies of sub-politics are moreover classified by Holzer and Sørensen (2003) into a continuum of passive versus active sub-politics. The risk society provokes "unwitting" and ergo *passive* (sub)-political effects, which, reflexively, produces an *active* sub-politics of "predominantly social movements" contending with risk (2003, 2.) Active sub-politicians identify as political, albeit informal or "non-institutionalized", agents,

---

[12] Sub-politics is reintroduced by Marres and Lezaun (2011, 7–9) in a special issue on "materials and devices of the public" to portray the "politics of artefacts", "in ways that are not just tacit, but virtually sub-legal" as a distinct strand of STS research. This approach is separate, and thus out of scope, to the political sociology of Beck articulated in this thesis.

[13] This refers to, in particular, the eruption of expertise studies in (Collins and Evans 2002), responded to by (Jasanoff 2003), (Wynne 2003), and (Rip 2003) in a seminal debate within the journal *Social Studies of Science* and surrounding the political consequences of pluralizing and de-objectifying expertise. Expertise studies in this thesis will be delimited to the analytical tradition of sub-politics.

[14] This thesis follows the tradition of Beck in sub-politics. However, another seminal theoretical approach to expertise, relevant to the thesis, is that of Actor-Network Theory, developed within STS under various titles (e.g. Callon 1984.) Problematizations of modernity, between the sociology of reflexive modernization and Actor-Network Theory, are explicitly confronted in a theoretical piece by Latour (2003) in the same journal issue as (Holzer and Sørensen 2003.)

whereas passive agents are political in the relativist sense, or "in the eyes of the beholder" (2003, 2.) These agents might not label their activities as politics or identify as political—yet there are political side-effects.[15]

Holzer and Sørensen reveal three modalities of sub-political influence, in buycotting, boycotting, and the "absorption of uncertainty." In *buycotting*, sub-politicians reward actors through economic support, while *boycotting* consists of sub-politicians withholding support that was previously constant (2003, 5–14.) The absorption of uncertainty describes the function of expertise in facilitating decision making by communicating reified, or 'absorbed', conclusions instead of ambivalent findings (2003, 13–17.) These three modalities, as sub-political action, complicate Beck's expectation for its tangentially political character: sub-politics as *quasi*-politics (2003, 16–17.) Instead, Holzer and Sørensen argue that the economic and techno-economic (expert) character of sub-politics should be the research aim of sub-politics. In the words of de Vries (2007), and building on Beck, the signal question is not "what is political in sub-politics", but what is non-political in sub-politics.

These modes return to the notion of individuals and individualization. Sub-politics elucidates forms of action beyond the institutional spheres of politics and non-politics

[15] Over the past decades, a number of empirical studies on sub-politics have been conducted. An exhaustive review is beyond the scope of this thesis. Many can be located on the passive-active continuum. Passive cases of sub-politics are clustered in techno-economic settings, such as: the aforementioned maternal blood testing in (De Vries 2007), business associations (Eden 1999), sustainability in the ready-made garment supply chain (Antonini, Beck, and Larrinaga 2020), and the rise of sexual health expertise in the UK (van Loon 2007.) Closer to the modern iron cage of politics are two additional studies, one describing the role of "sub-political policy entrepreneurs" within the EC bureaucracy (Westlake 2024) and another following local youth workers in Eastern Finland in a "subpolitics of multiculturalism" (Kivijärvi 2010.) On the other end of the spectrum, active cases of sub-politics surround developments in civil society, most often politicized controversies and activism. These include a "new social movement" mobilizing against air pollution in Hong Kong (Chan 2008), climate activism in Singapore (Teo and Amir 2021), a "modern imaginary of science and politics" in memories of the BSE controversy in South Korea (W. Lee and Kim 2022), anti-sweatshop activism in the case of Nike's labor practices (Knight and Greenberg 2002), the anti-poverty movement in Japan (Shin 2016), and the Transition social movement on localization (Stevenson 2012.) Attention to local scenes, often set against concerns of globalization, are found through a controversy around hazardous chemical waste disposal in Sydney, Australia (e.g. Benn, Brown, and North-Samardzic 2009), the "subpolitics of performing place" in the Benelux border region of Gensschap (Buizer and Turnhout 2011), and local communities as "informal regulators" in Viet Nam (Phuong and Mol 2004.) A tertiary theme of active sub-politics has emerged to analyze roles of the media, either through new ways of politicking during political campaigns on social media, for instance with Twitter, (Sreekumar and Vadrevu 2013), or the prominence of informal sub-politicians in patient advocacy contra anti-abortion groups in science news coverage of a controversy on "therapeutic cloning" in the UK (Jensen 2012.) Finally, Whittington and Yakis-Douglas (2020) situate their discussion around managed and unmanaged "open strategy" in collective (e.g. walkouts), as opposed to individual sub-political action (e.g. whistle-blowing), in the corporate setting, which suggests another interstitial location of relativist, ambivalent sub-politics.

and into the presumed separation between public and private life. Private or everyday life is placed into the frame of sub-politics through Bakardjieva's (2009) concept of "subactivism" in a study of household internet use. Subactivism, conversely with activism, is defined by everyday practices which are not performed intentionally as politics, but nonetheless could become so. This sphere is a "layer" of politics in everyday life (2009, 13), as demonstrated by **Figure 3**, consisting of ethical decisions projected as politics. For Bakardjieva (2009, 7),

> the very self-identification of the individual as an actor taking sides and choosing positions and courses of action vis-à-vis debates and clashes of values and interests in a larger social world represents an elementary instance of subactivism.

Subactivism alludes to a significant potential of ethical action in everyday life.[16]

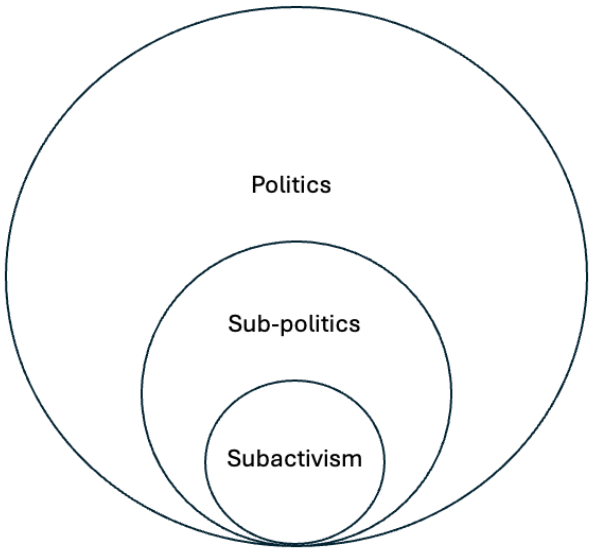


Figure 3. Tripartite Venn diagram of politics in risk society

Research questions

These developments, while helping to express contours of sub-politics, are not the specific focus in this thesis. Instead, it is centered on Beck's earlier presentation. Beck

[16] There are additional empirical studies either referencing or amenable to the perspective of subactivism which utilize sub-politics. Eide and Knight (1999) investigate the rise of "service journalism" in commodified problems of everyday life, while Bakardjieva's (2009) preferred domain of the Internet is further explored by separate studies of online piracy in Sweden (Lindgren and Linde 2012) and Estonia (Vihma 2016.) Ben-Porat's (2009) work on contemporary Israeli society, centered around the role of religion in public life, can be read through subactivism. Residential city-planning, "a local ecological dream", and its consequences for everyday life are central to the case of sub-politics in Local Agenda 21 in Denmark (Gram-Hanssen 2000.)

concludes his presentation of sub-politics by considering the dissimilitude between polity, policy and politics in the moment of reflexive politics (1997b, 103–4.)

This thesis enlists a research program for studies of sub-politics that builds on the pillars of sub-polity, sub-policy and sub-politics. One avenue is the character and organization of a *sub-polity*, including its relation to power. Two is the examination of *sub-policy* goals, its placement of action, and ability for objectification into "non-policy." Three is the emergence of "organizational forms and forums" of *sub-politics* to "trace" the power dynamics (cf. De Vries 2007.) This emergence, at the center of the theoretical framework, is visualized below in **Figure 3.** Below, in **Table 3**, are the three research questions anchoring the thesis, and that will be addressed by the thesis.

Table 3. Research questions

Research Question 1	How are the *sub-polities* of nanosafety and innovation organized and instituted?
Research Question 2	How are *sub-policies* articulated through *sub-polities*?
Research Question 3	How are *sub-politics* expressed by *sub-polities* and *sub-policies* of nanosafety and innovation?

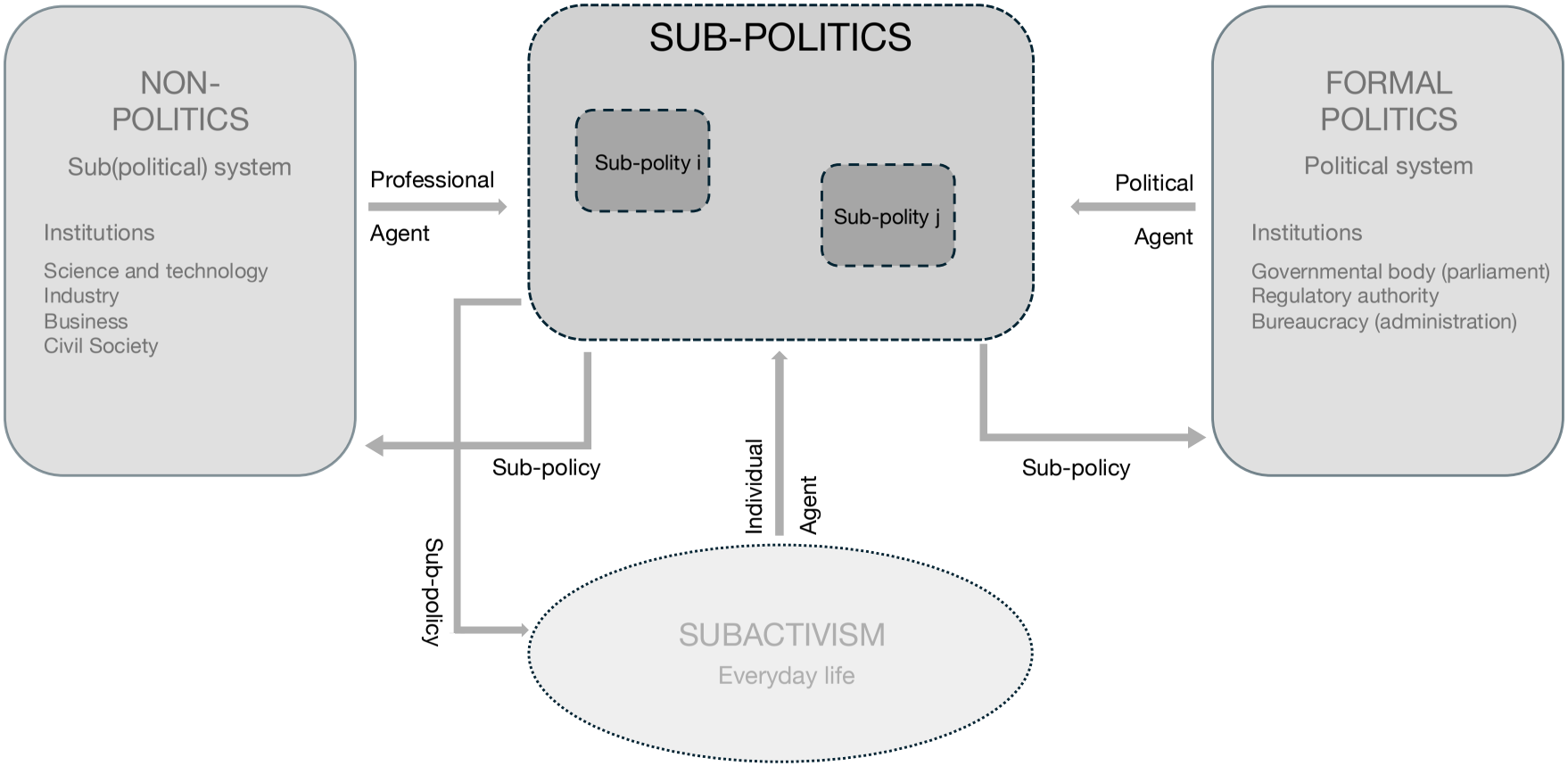


Figure 4. The epoch of sub-politics

FOUR/ **PREVIOUS RESEARCH**

This section applies the Beckian framework pillars (described in Section 3) of sub-politics—that is, sub-polities, sub-policies, and sub-politics—to previous research on nanotechnology governance. In the 1990s, as a Beckian tradition surrounding *Risk Society* promulgated within sociology, a parallel trend emerged from political science. This tradition is centered around concepts of governance versus government. Studies of governance, however, while largely the same phenomenon, are not part of the Beckian framework.[17] The section begins by reviewing this parallel turn to governance, established through risk regulation, and its translation of three regulatory challenges in the nanotechnology context. This introductory digression into political science is necessary to review as an empirical contextualization of the previous research that will be read through sub-politics. The subsequent **previous research** is foreshadowed and summarized below in **Table 4**.

Table 4. Summary of previous research applied in framework

Framework pillar	Explanation	Example from previous research
Sub-polity	Spaces *where* sub-politics occurs, outside of formal political system, like stakeholder dialogs	Public engagements - UK Nanodialogues (Stilgoe 2007) Third-party organizations - EC ObservatoryNANO (Åm 2013) Stakeholder dialogs and workshops - NanoKommission in Germany (Pfersdorf 2012) Stakeholder and expert perceptions - Precautionary Principle (Saldívar-Tanaka and Hansen 2021) Studying (nano)scientists and reflexivity - Integrating RRI in nanosafety (van Hove and Wickson 2017)

[17] As an exception, Trone-Holst and Stø apply a risk society framework to the governance of nanotechnology (2008.) They enlist stakeholder interviews in Norway regarding the potential use of the precautionary principle as a governance approach.

Sub-policy	Decisional outputs (the *what*) of sub-polities, often typified by soft regulation as principles, tools, guidance, or approaches	Codes of conduct - EC Code of Conduct for Responsible Nanoscience and Nanotechnologies Research (Dorbeck-Jung and Shelley-Egan 2013) Best practices and principles - Corporate Social Responsibility (Chris Groves et al. 2011) Information and coordination tools - Informal governance platform (Roig 2018) Standards and standardization - ISO Technical Committee 229 (Delemarle and Throne-Holst 2013) Decision support, guidance and compliance - Cenarios certification standard (Widler et al. 2016) Safety-by-Design - Conceptual emergence (Kelty 2009)
Sub-politics	Political features (the *how*) of sub-polities that mediate and generate sub-policies, like organizational models and conflict	Nanotechnology, nanomaterials and morality - Governance fora of agora and arena (Swierstra and Rip 2007) Controversies and debates - Drexler-Smalley debate (Kaplan and Radin 2011) Interrogating research projects and outcomes - Tensions in public engagement (Delgado, Kjølberg, and Wickson 2011) Expectations and uncertainty - Taxonomy of uncertainty (Christopher Groves 2009) Affect Politics of enthusiasm (Kearnes and Wynne 2007)

Introduction: the governance turn in risk regulation

In recent decades, notions of 'governing' from government have spread, in attempting to co-evolve with previously *governed* institutions, rather than govern from above.

Government no longer merely 'rows' (exclusive direct intervention) governed institutions, as it experiments with 'steering' or indirect approaches (Dorbeck-Jung and Shelley-Egan 2013, 56.) This turn to decentralized governance, often referred to as "The New Governance" (Rhodes 1996), has generated a panoply of new modes of governance that can partly be considered in terms of risk regulation.

Regulation, especially in the EU (Hey, Jacob, and Volkery 2007), has pivoted towards these new modes. Together, they seek to transcend the "command and control" paradigm of earlier environmental regulation (Sinclair 1997; in nanotechnology, see Stokes 2013.) These are frequently categorized under soft law, in contrast to hard law (e.g. Bowman and Hodge 2008a, 6.) In science and technology governance, this is termed soft regulation, that "generally refers to a broad group of normative instruments, such as resolutions, declarations, guidelines and recommendations, and codes of practice and conduct" (Arnaldi 2017, 4.) This amalgam of old and new governance that characterizes the governance landscape can be termed *hybrid*, or 'hybrid regulation' (Bowman and Hodge 2008b, 478, 484), whereas Rip emphasizes the "strong bottom-up character" in the phrasing of "de facto governance" (2020, 108–10.) The regulator–regulatee relationship becomes more complicated, and less adversarial, under new governance, with complementary organizations proliferating in this "networked regulation" (Wesdorp and Klijn 2024, 1.) [18] The European policy discourse endorses soft regulation under the auspices of the "Better Regulation" concept (see European Commission 2001; recently see 2021.)

Steering through soft regulation can provide some benefits over government. As suggested by Bowman and Hodge (2008b, 476–79), steering approaches can offer speed and flexibility to innovate regulation (often derided as slow and rigid) to address difficulties with emerging technologies. Soft regulation aims to decentralize governmental regulatory authority, which could be more efficient and rely on stakeholders, like the above regulatees, who are ascribed greater regulatory capacity.

Three regulatory challenges

There are at least three types of stylized challenges of regulation to the new governance. These are efficacy (ensuring regulatory outcomes), uncertainty (acting without a clear horizon) and legitimacy (ensuring the acceptance of outcomes by both stakeholders and government.)

[18] See, for example, the recent volume on contemporary regulatory practice (Le Coze and Journé 2024.)

First, soft regulations have an efficacy challenge: they are voluntary and non-binding, as opposed to hard law and formal, state regulation. Regulatees must therefore be convinced to apply soft regulations. Studies, especially regarding nanotechnology (Stokes 2013, 31–32), document generally low uptake rates, owing to *inter alia* compliance costs, low awareness levels, or divulging confidential data.

Second, on the uncertainty challenge, soft regulations are mutable and cannot foreclose, in a *de jure* manner, the possibility of finalized regulation. Amongst others, Héritier and Lehmkuhl (2008) have explored this problematic of regulatory uncertainty as "the shadow of hierarchy." For emerging technologies, like nanotechnology, there are further uncertainties concerning market, trajectory, science, information and transnational harmonization. Stokes establishes the "demand for command" in nanotechnology, against new governance, that offers clarity to regulators and regulatees in novel markets (2013, 38.) Then there is temporal uncertainty, in seeking to regulate uncertain technology trajectories based on unpredictable contingencies (Doorn 2013, 30–31.) Soft regulations are also limited by scientific uncertainty, that is, epistemic limitations preventing risk-based regulation (e.g. Bowman and Hodge 2009.) Information, a prerequisite to address scientific uncertainty through decision making, opens up new governance to novel stakeholders proffering information who reside beyond the regulator—regulatee relationship (Stokes 2013, 38.) Finally, harmonization uncertainty unsettles notions of the preferred regulatory domain with a globalized nanotechnology industry amidst harmonization demands to simplify compliance across legal boundaries (Falkner and Jaspers 2012, 46–50.)

Third, the legitimacy challenge rises from the authority of regulatee, in the degree of (public) acceptance of the soft regulation. Regarding nanotechnology, Arnaldi (2017, 4–5) explains that soft regulations can be seen as legitimate amongst participating regulatees due to their increased engagement generating an information advantage. Soft regulation can be conceptualized as a continuum, moving away from hard regulation towards self-regulation solely reliant upon regulatees, but dogged by the public legitimacy deficit (Bowman 2014, 319–20.) In between, there is co-regulation that involves regulators or third-parties, which can provide legitimacy from either legal or moral authorities (e.g., NGOs) independent of regulatees. Meta-regulation, additionally, can generate legitimacy from processes to regulate the regulation, along this soft regulatory continuum (see Dorbeck-Jung and Shelley-Egan 2013, 57–59.)

Legitimacy, seen from nanotechnology, is interconnected with these challenges and the larger EU political project. This can be demarcated into input, output and throughput legitimacy. Ehnert (2015, 49–50), in a legal review, explains that input legitimacy

derives from direct regulatee or public involvement in regulation-making, on top of indirect representation through the political system. Output legitimacy means regulatory efficacy and *ex post* accountability of the regulator. The extended uncertainty challenge in regulating nanotechnology leads to Ehnert's assertion that, "the 'common interest' of the citizens and the accordant 'effective solution' to the nano problem is no longer obvious. Output legitimacy, therefore, conditions input legitimacy" (2015, 50.) For the EU project, a nascent European political identity makes input legitimacy fickle, with preference for output over input. Separately, Forsberg additionally stresses "throughput legitimacy", as "how legitimate is *the design* of the development process", opposed to input *participation* and output as *outcomes* (2012, 6.)

Sub-polities of nanotechnology governance

The first dimension of the Beckian framework is the sub-polity. Previous research on nanotechnology governance which interrogates spatial, or organizational, aspects, is introduced and reviewed as instances of sub-polities as a way to read the literature through Beck. This literature can be seen as attempts to answer the question of *where, and in which forms, is sub-politics occurring.*

There are at least five discernable genres of sub-polities investigated previously in nanotechnology. First are deliberative public engagements with nanotechnology as experiments in governance. Second are third-party organizations that transcend the orthodox regulator-regulatee relationship. Third are stakeholder initiatives inaugurated to address governance challenges. Fourth are various studies to explore perspectives on nanotechnology from experts and assorted stakeholders beyond either science or the political system. The fifth genre recounts findings from studies of scientists, as opposed to other stakeholders, in nanotechnology.

Public engagements

Public engagements emerged for two key reasons (see e.g. Groves 2011.) They are envisaged to forestall the trend towards techno-tragedies, such as the representative cases of nuclear power and GMOs recounted under **research context,** that injects perceptual risk—and potential sub-politicization– into investments of research and innovation. Publicly engaged nanotechnologies are also hoped to be more effective, in upstream exposure to potential future users (Wilsdon and Willis 2004), as a response to the eponymous Collingridge Dilemma (1982.) In either case, scholars have refined

novel tools for public engagement by constructing or analyzing various sub-polities since the 2000s.[19]

In the UK, there was a citizen jury called 'NanoJury UK' (see Rogers-Hayden and Pidgeon 2006; Pidgeon and Rogers-Hayden 2007; Doubleday 2007a) and later on a series of 'NanoDialogues' run by the Demos think-tank (see Stilgoe 2007.) Macnaghten and Guivant (2011) compare public engagement between the UK and Brazil, suggesting greater UK public skepticism to (nano)science and technology. Burri, in a study from Switzerland (2007), uses ethnography to explore participant perspectives during a citizen panel '*publifocus*' on nanotechnology, health and the environment. In Slovenia, the 'NanoŠmano Lab' offers a rare case study of a bottom-up "hackerspace model of governance" through public engagement via "disruptive prototypes" (Kera 2012, 1.) Jansma and colleagues (2021a) develop a novel method of Dutch co-creation citizen workshops on nanotechnology and health as part of the GoNano project, referenced in the **introduction,** that turns directly to fostering innovation. From Australia, Kyle and Dodds (2009) review multiple initiatives, including the UK-inspired 'Nanodialogues' repeated in Queensland, which were often supported by the Australian government (see Katz et al. 2009 for a viewpoint from the responsible agency.) Munshi and colleagues (2016) document an indigenous citizen panel in New Zealand, pressing for a cultural and indigenous turn in public engagement studies. Turning to the US, Kleinman and colleagues (2011) emphasize the difficulties in recruiting participants to two linked consensus conferences. Two more engagements here are a dialog on nanotechnology and religion (Milford and Wetmore 2013) and 'NanoFutures', built on a virtual website interface instead of the physical variety (Selin and Hudson 2010.) While public engagements in nanotechnology are a prolific genre, they are tangential to the sub-polities analyzed in this thesis.

Third-party organizations

Third-party organizations in nanotechnology can be grouped into those bolstering innovation (see Howells 2006), generating expectations, or environmental NGOs seeking to steer governance.[20] The literature here can be read as instances of sub-polities in either the *role and operation* of the intermediary or in its *episodic* interactions with

[19] See (Delgado, Kjølberg, and Wickson 2011) for an itemized review of public engagements in nanotechnology.

[20] The term NGO is used as a synonym to civil society organization, or CSO, in this thesis, without any clear distinction deployed by the literature. In nanotechnology, environmental NGOs have been referred to as "environmental reform organizations" in the sense of EHS reform organizations that advocate "greater attention to EHS issues and related policy reforms" that extend beyond NGOs (Hess 2010, 3–4.) Environmental NGOs will be used in the thesis to focus on the exoteric terminology.

other stakeholders that can elucidate complexity, establish markets, or project moral authority.

Regarding innovation, Falkner and Jaspers (2012, 19–23) recount regulatory innovations of transnational intermediaries, like the OECD. In a case study of UK nanotechnology, Mount and colleagues (2015) assert the enabling role of intermediaries in accruing knowledge processes and capacities. More concretely, Åm (2013, 1–2) stresses the "ambiguous governance context" of nanotechnology in a study of the EU-oriented intermediary 'ObservatoryNANO', with the remit as a novel organizational form to update policy-makers with the latest developments.

Regarding expectations, "promissory organizations" are defined by Pollock and Williams (2010) to fulfill another role. Instead of organizing complex technoscientific knowledge in innovation, this type specializes as "independent third party organisations" in the "business of *technological expectations* [original emphasis]" that can performatively establish markets for emerging technologies through organizing promises (2010, 1–2.) While this definitional study surrounds the Gartner group as an "industry analyst" in information technology, Beckert's (2021, 11–13) review of "organizational prospection" adds further examples to this forecasting institute, in credit rating agencies, advertising agencies and financial firms. In nanotechnology, there is a greater focus on the expectations than their organization (from **research context**, see Rip 2006.) However, Ebeling (2008, 17–19) intuits the promissory organization, during an investigation of the expectation work of Lux Capital (financial firm) and Lux Research (spin-off forecasting institute) to manufacture hype and perform a market for nanotechnologies with questionable independence from direct investors.

Regarding NGOs, Wang posits that while they could transfer the above public engagement outputs to formal government decision-making, generating input legitimacy, a series of interviews finds frustration in the process and public disinterest (2016, 1.) Wehling moves the focus from these "standardized models of ''invited'' participation", to "uninvited" NGO engagements, contending that they can offer greater legitimacy and impact, with examples from patient advocacy, environmental and consumer oriented groups (2012, 1.) Seifert and Plows support this general conclusion through a recollection of NGO organization from against biotechnology to "anti-nano", declaring "the foretold backlash, however, never occurred" (2014, 1.) On the level of NGOs themselves, two established groups have reflexively presented their standpoints on nanotechnology: (1) Friends of the Earth Australia, advocating for using NGO moral authority to define the frame of nano-ethical assessment (Miller and Scrinis 2010) and (2) Environmental Defense, reasoning that more public investment and soft

regulation is essential (Balbus et al. 2006.) Environmental Defense plays a seminal role in attempting a novel soft regulatory mechanism through its multi-year partnership with the chemicals giant DuPont—an episode well-described by Krabbenborg (2013; 2020.) This NGO effect on governance is detailed by (Bowman and Hodge 2010, 1–2), comparing the partnership and efforts by the earlier introduced NGO, ETC Group, to conclude that NGOs are positioned to fill the nanotechnology governance void left by governments, but not without contested input legitimacy. NGOs are moreover theorized in "regulatory governance" scholarship in a wider organizational role of "surrogate inspectorate", with above strategies of information gathering and activism, coupled with "legal action" and "blame activities" on regulators or regulatees (Wesdorp and Klijn 2024, 4–5.)

Stakeholder dialogs and workshops

Stakeholder dialog settings refer to the creation of multi-stakeholder fora—beyond simply regulators and regulatees or scientists–generally intended to assist in nanotechnology governance by mediating through the uncertainty challenge. Studies depicting these dialogs, as processes or outcomes, offer another genre of sub-polities. While some dialogs are self-established or instituted by government, others are managed by external scholars.

The clearest example of a nanotechnology stakeholder dialog, chronicled by previous research, is the German case of the NanoKommission (see Pfersdorf 2012.) Åm (2011b) uses interviews from participants to demonstrate the role of trust and consequences of consensus-seeking for governance in these arrangements. In a self-organized Italian stakeholder dialog, Mirabile and colleagues attempt to form a sustained sub-polity for nanotechnology occupational health and safety that reflexively reinforces the perceived need for consensus (2014, 1.) Isaacs and colleagues (2015, 1) recount their experience of an unscripted stakeholder dialog on nano-manufacturing environmental health and safety, finding "hopeful" stakeholders working towards a new governance framework. Next, in an EU project on RRI, Heltzel and colleagues utilize stakeholder dialogs to probe five disparate frames of responsiveness and dynamics of conflict avoidance, polarization and reframing to mitigate conflict potentials (2022, 13–16.) Returning to the GoNano project, Jansma and colleagues (2021b, 1) describe another phase (integrated with public engagement) of stakeholder workshops based on co-creation, illustrating the potential trade-off between prioritizing the input legitimacy of inclusivity versus the efficacy of "added value."

Stakeholder and expert perceptions

Studying stakeholders in nanotechnology governance is a common theme. This fourth genre pivots to studies (i.e. surveys and interviews) of stakeholder and general expert perceptions that can involve scientists but are not external dialogs or workshops. Perceptions of risk and responsibility, specific issues within nanotechnology and the role of industry are highlighted. These studies are frequently intended to offer a suggested expert solution to a governance problem, and as such, can be construed as a series of sub-polities with these solutions as sub-policy.

On risk and responsibility, Porcari and colleagues find, in a large international stakeholder sample, a converging consensus in the need for scientific information on nanomaterial impacts, "robust regulation" and nanomaterial specific guidance documents (2019, 1.) Malakar and Lacey (2023) conduct interviews to interrogate the scope of responsible innovation in risk analysis, showing how "inclusion and reflection" principles could open up conceptions of risk. One specific stakeholder issue is the regulation-innovation relationship for nanotechnology in food and agriculture, exemplified through a combined study using expert insights from an online survey (Grieger et al. 2021) to identify a spectrum of views where soft regulatory practices of responsible innovation could present alternatives (Merck et al. 2022, 1.) Another issue for nanotechnology is the question of applying the precautionary principle to address scientific uncertainty. Two studies interrogate expert views on the issue, with one interview study (Saldívar-Tanaka and Hansen 2021, 1) finding broad support but also its perceived "stigmatization" as unscientific and anti-innovation, whereas an earlier stakeholder study posits three possible "restrictions" ("regulating nanomaterials as new chemicals; planning end-of-life management of products containing nanomaterials; and presumption against release of manufactured nanomaterials into the environment") under the principle to facilitate governance (Throne-Holst and Stø 2008, 13–14.) Similarly, Köhler and Som (2008, 1) show how nanotechnology innovators are not very reflexive on environmental risks, but worried about a potential public backlash. Shelley-Egan and Davies interview nano-industry representatives on the responsible development discourse, clarifying dueling framings of risk and social responsibility (2013, 14–15.)

Studying (nano)scientists and reflexivity

A final genre of sub-polities is centered on understandings and perceptions of scientists in nanotechnology. Perspectives on risk and responsibility feature again in ethnographic studies and with interviews, in contrast to a social scientist reflection on previous

engagements. These studies are portrayed as analogous sub-polities to the above fourth genre—albeit with the empirical delimitation to scientists.

Two ethnographies explore the situatedness of nanoscientists. In the context of public engagement, Doubleday (2007b, 9) proposes an analytical move from "upstream" to "upstreamness" in finding effective deliberative fora, which is invoked by Johansson and Boholm's ethnography emphasizing disparate disciplinary perspectives between upstream promotion of innovation and downstream preoccupations with "uncertainties and unpredictability" (2017, 1.) On reflexivity, Schuijer and colleagues (2021) review their own engagement and "juggling" of five separate roles in a public engagement project that require greater focus.

Various (generally interview) studies help advance a conversation on ambivalence in attending to risk and responsibility. Regarding the nanomaterial graphene, Arvidsson and colleagues identify ambivalent constructions of risk by scientists that preclude responsibility-taking by minimizing potential risk and uncertainty (2018, 1.) Kjølberg and Strand reveal little awareness in the EC code of conduct on 'responsible nanosciences and nanotechnologies research', instead articulating three "broad notions" in the "traditional social contract", "deliberation across levels and sectors", especially between science and policy, and the "awareness of moral choices" (2011, 11–14.) Later, van Hove and Wickson (2017, 13) interview nanosafety scientists on enactment of RRI, detailing hinderances in terms of physical constraints and culture conflicts with institutionalized "good science." Åm extends these findings in examining the translation of this type of "science governance" by scientists to propose various "coping strategies", with the conclusion that achieving enactment, or uptake, will require "creating possible conditions for new practices" (2019, 1.) This pattern is termed "a failure of meta-governance" (Åm 2019, 14), comparable to the meta-regulation defined earlier (cf. Dorbeck-Jung and Shelley-Egan 2013.) Another study on translations of responsibility by nanoscientists from Glerup and colleagues (2017, 13–14) expound on the irrelevance of RRI as a "policy discourse", but nevertheless ascertain a series of "bottom-up responsibilities" amongst competing demands for attention in the political economy of science. These authors refer to these divergences, in an earlier study, as multiplicity between "an expansive version", and "safety, and not much more" (Davies, Glerup, and Horst 2014, 15.)

Sub-policies of nanotechnology governance

The second dimension of the Beckian framework is sub-policy. Sub-policies are understood as instances of soft regulation or informal policy (outputs), that can involve

government but lack legal compliance mechanisms (i.e. not legislation.) Reviewed sub-policies can be typologized in two facets: (1) studies on *normative* steering, aiming to render legitimate governance (via attending to social responsibility), and (2) *instrumental* studies that problematize and document the emerging governance (usually to resolve the regulatory challenges of efficacy and uncertainty.) Put together, these studies seek to answer the question of detailing *how sub-policies evolve in nanotechnology governance.*

Sub-policies on science and technology, while now abundant, did not begin with nanotechnology or the preceding techno-tragedies. In terms of the normative facet, commonly grouped as ethical, legal, and social sciences (ELS), they are frequently cited as emerging in the Asilomar conference of 1975 (Braun and Müller 2024, 3–4.) Scientists specializing in the nascent field of recombinant DNA gathered to form a reflexive sub-policy (i.e. self-regulation) to proceed with precautionary measures—but without any non-scientist stakeholders. More recently, a review of EU funding project proposals in "potentially controversial areas" (including nanotechnology) finds these ELS aspects and stakeholder integration to remain marginal (Rodríguez, Fisher, and Schuurbiers 2013, 1.) As expected, Shelley-Egan and colleagues focus on reviewing actual RRI "initiatives" in nanotechnology, presenting myriad "devices of responsibility" that seem to problematize research and innovation environs, but lack either uptake in quotidian processes or institutionalization (2018, 17–18.) [21] Arnaldi (2017, 8) summarizes developments in soft-regulation, beyond the RRI ambit, deploying interviews of nanotechnology researchers and firms to understand the compliance dynamics through the two dimensions of "rules" and "actors." This culminates in a call to investigate third-party organizations in their influential role to promote compliance, and by extension, efficacy of soft-regulations (2017, 12–13.)

The literature unfolds with at least six genres of research on sub-policies in nanotechnology governance. The first two genres surround normative steering, in terms of ethical 'codes of conduct' and the industry-oriented logic of 'best practices' typified by Corporate Social Responsibility (CSR) strategies. Remaining genres explicate a variety of instrumental approaches to further governance. These are devices to manage nanotechnology information, and studies analyzing soft regulatory standards or processes of standardization. Two final genres foreground innovation, with examples of practices and guidance, followed by the approach of Safety by Design.

[21] Laurent also applies a device-oriented approach ("agencement") to understanding the construction of both responsibility (with)in EU markets for nanotechnology (2012, 14.)

Codes of conduct

The EC Code of Conduct is symbolic of the genre. While Kjølberg and Strand (2011) enlist the Code to study perceptions of responsibility, Dorbeck-Jung and Shelley-Egan (2013, 1) evaluate it to suggest "responsibilization" as a precursor to self-regulation. To nurture responsibility, they posit that practices of meta-regulation ("trust-building activities", "links with rationality of self-regulators" and "activities encompassing vigilance, oversight, enforcement and accountability") are critical to regulatory efficacy, but find them to be absent or lacking. Bowman and Hodge (2009, 15–16) map various codes of conduct, detailing five examples (including the above EC Code), to discuss persistent regulatory challenges—especially limitations to legitimacy (dearth of legal or independent authority and compliance) and efficacy (dearth of meta-regulation and compliance.) Despite the limitations, they stress the capacity of codes to produce governance effects in anticipation of regulation that ensure their utility. Beyond these extant codes, Shew drafts a sample of one for nanotechnologists, in the dual sense that codes can help solidify nascent professional identities, like the nanotechnologist (2009, 1–2.)

Best practices and principles

In contrast to ELS and RRI specifically, CSR offers management tools to the nanotechnology industry, where the uncertainty challenge is key. In this way, Lee and Jose endorse a series of best practices, risk research, an "early warning" system and stakeholder collaboration to reconcile the trade-offs between corporate self-interest and CSR (2008, 1, 12.) Groves and colleagues later expand on this conversation through a large UK study based on corporate documents, interviews and a survey of the nanotechnology industry (2011.) They expect that applying CSR to responsible innovation will favor the "positive social force" model over the more minimal "do no harm"—a layout comparable to the multiplicity approach of responsible development recounted by Davies and colleagues (2014), above. Returning to the topic of nanotechnology in food and agriculture, Merck and colleagues (2022, 5) propose responsible innovation as a best practice through institutionalization pathways: "internal organizational norms", "developing standards", conditioning funding on it, or implementing legal mechanisms. This can be read as a response to above institutional critiques (e.g. van Hove and Wickson 2017; Shelley-Egan, Bowman, and Robinson 2018.) In the NanoCap project, van Broekhuizen and Reijnders (2011, 9–10) convey joint resolutions of a large European deliberation (with universities, trade unions, and environmental NGOs) to "operationalize the precautionary principle" through a set of seven "building blocks", namely best practices. These are itemized as "no data → no

exposure and no data → no emission", "reporting of the content and type of nanomaterials in products", "registration of workers possibly exposed to nanomaterials", "transparent communication about known and unknown risks", "derivation of workplace exposure limits", "development of an early warning system" and "premarketing approval for all applications and nanotechnologies and nanomaterials."

Information and coordination tools

Scientific uncertainty, as one aspect of the regulatory challenges, is partly managed by tools, as sub-policies, that coordinate and organize information on nanomaterials and nanotechnology in general. The **research context** has summarized some central findings from databases of nano-enabled products, exemplified by the Nanodatabase (see Hansen, Hansen, and Nielsen 2020.) The Nanodatabase itself uses risk categorization, specifically NanoRiskCat, where both "exposure potential" and human and environmental hazards are evaluated for specific nano-enabled products (Hansen, Jensen, and Baun 2014, 1.) Five dots are shown for a nano-enabled product: "[t]he first three dots refer to the qualitative exposure potential for professional end-users, consumers and the environment, whereas the last two refers to the hazard potential for humans and the environment" (2014, 1.) Recently, the tool has been revisited for advanced materials in SSbD, under the name AdMaCat, to screen for safety and sustainability in the design phase (Rubalcaba Medina et al. 2024, 2–3.)

Bowman and Ludlow, in an earlier study, propose a voluntary nanomaterial registry to begin the coordination work, gather environmental health and safety data, and forestall government mandates (2009, 11.) Mcgovern describes an anachronistic mechanism, namely, the commodity exchange, as a way to further establish markets for nanomaterials given the production difficulties, which is elaborated in the case of the INSCX Exchange (2016.) Informal platforms for nanotechnology governance serve as another mechanism, in an account by Roig (2018, 5), that attempt to connect risk assessment, management, and decision making and use "co-regulation" (including co-evolution between regulators and regulatees) given the presiding uncertainty and risk-based approaches.

Standards and standardization

The literature on standards is bifurcated into two topics. One stream scrutinizes the finalized sub-policies of nanotechnology standards. Another stream delves into the

constitutive sub-policy making of standardization processes that imbue the eventual standards.

"Voluntary consensus standards" for nanotechnology simplify and codify either technical or management aspects that are built on (private) technical expertise, rather than (public) regulatory authority (Bell, Garsson, and Tomsen 2013, 1.) In a review, Bell and colleagues (2013, 5–7) reiterate that standards attend to the efficacy and uncertainty challenges, itemizing the work of the central International Standardization Organization (ISO) on terminology, measurement, and EHS. Goebelbecker and Albrecht (2016, 12–13) interrogate the introduction of nanotechnology into the "European food and feed sector", detailing uses of the ISO risk management standard and calling for an "active and preventive risk defense", over mere compliance of regulations or *soft* standards. A third study starts from this ISO standard, as codified in Mexican regulation, comparing it with non-ISO national OHS regulations to suggest the standard is less protective and congruous with a soft, neoliberal rationality (Foladori 2017, 1–2.) Codifying soft standards for nanotechnology into national regulations, as is common according to Foladori, is embedded with politics.

On standardization, Roubert and colleagues recount multiple "standardized methods" developed in a research project to harmonize through the uncertainty issues in disparate experimental practices amidst regulatory and standardization gaps (2016, 1.) Two further studies transition the discussion from instrumental gaps to more normative issues in structures of standardization using the case of ISO Technical Committee 229. For Delemarle and Throne-Holst (2013, 16–17), participating in the Committee, standardization is an extension of regulation-making that acquires input legitimacy from members and seek to yield a "collective vision", akin to Beckert's "promissory legitimacy" (cf. 2020)—beyond mere production of standards. Yet for Forsberg (2012, 19), with an analogous participatory approach on TC 229, standardization work has the "window dressing" and input legitimacy of stakeholder participation, but struggles to address the scientific uncertainty (despite the harmonization ambitions.) Throughput legitimacy is moreover contested from the practical reliance on industry members (over public authorities) and limitations of requiring consensus necessitating compromise. Kica and Bowman (2012, 45–47) compare TC 229 with the OECD Working Party on Manufactured Nanomaterials, highlighting health and safety standards, emphasizing a consensus-based approach against a "closed club" environment lacking throughput legitimacy (echoing Forsberg) with uneven accountability to stakeholders or a wider public. Also reflecting on standardization process experiences, Wickson and Forsberg propose standardization as a "backgrounded interstitial political space", where RRI practices should be applied to target actual innovation domains (2015, 19–20.)

Decision support, guidance and compliance

Another sub-policy category is decision support and guidance, which can generate some certainty to professionals, given the scientific and regulatory uncertainty. These can be more contextual, ambiguous, and involve co-regulation with regulatory authorities or other stakeholders, without legal force, but are still replete with the efficacy challenge of compliance, highlighted by Feitshans (2021, 1.) This challenge is underscored by Engeman and colleagues' (2013, 1) survey results of the nanotechnology industry on reported governance practices, revealing low awareness on nanomaterial specific guidance and downstream product stewardship and waste management practices, besides the problem of locating smaller nanotechnology firms. One tool, named Cenarios, functions as the first "risk management system" or "certification standard" for the industry (i.e. nanomaterial manufacturers and processors) that combines quantitative and qualitative risk practices, with independent auditing by the certifier TÜV SÜD that could transfer industry liability to insurers (Widler et al. 2016, 14–15.) Cenarios itself is a module for a wider decision support system (the Sustainable Nanotechnologies Decision Support System), developed to assist industry "in the context of compliance with formal or informal regulations" but is moreover proposed as a novel, open source support for international governance (Malsch et al. 2018, 12–13.) Life cycle assessment is also advocated as "holistic assessment tools" to bring a (environmental, economic, and social) sustainability perspective to decision support in nanotechnology (e.g. Meyer and Upadhyayula 2014, 14.)

Regarding guidance examples, van Broekhuizen summarizes the establishment of nano reference values through a stakeholder workshop as a precautionary threshold value to manage occupational exposure in lieu of formal limits (2012, 8.) [22] A subsequent study finds companies driven and willing to be proactive and seeking out compliance mechanisms to demonstrate precaution (van Broekhuizen and Dorbeck-Jung 2013, 1.) The compliance issue is later problematized in a study comparing three instruments, the nano reference values, plus the BASF Code of Conduct and a German public-private guidance, which demonstrates the need for "capacities" of available and appropriate devices, notwithstanding enlisting technological expertise (Reichow and Dorbeck-Jung 2013, 6–8.) [23]

[22] For a detailed presentation of nano reference values, see (Van Broekhuizen et al. 2012.)
[23] To be precise, these additional mechanisms are titled "BASF Code of Conduct Nanotechnology" and the German partnership, between BAuA (German Federal Institute for Occupational Safety and Health) and VCI (German Chemical Industry Association.)

Industry associations and liability insurers serve as additional novel drivers able to promote compliance. Reichow examines documents from the German VCI on nanotechnology, introduced above, intending to describe its collaborative, co-regulatory activities (2017, 21–23.) The study postulates that traditional notions of regulatory efficacy are *per se* ineffectual against the persistent uncertainty challenge, intuiting the business authority role (and throughput legitimacy) for industry associations that can facilitate collaboration and compliance by understanding regulatee positions and nurturing trust (emphasized earlier by e.g. Åm 2011b.) Marchant focuses on the compliance issue in nanotechnology soft regulation, suggesting that compliance can provide protection from legal liabilities (against Feitshans 2021) where regulations are lacking, and by highlighting compliance to lessen insurance premiums (2014, 1.)

Safety by Design (SbD)

The reviewed sub-policies tend to implement and improve new governance of nanotechnology through the later downstream phase, in places dominated by the regulator-regulatee relation. Safety by Design (SbD), as a "by design" approach, moves this logic upstream into design and innovation processes by incorporating early risk assessment and cognate tools, which can promote interdisciplinary and inter-institutional collaboration, build trust, and "enable systemic learning" to ensure efficacy, contra formal regulation (Miettinen 2021, 17.) In an early prospectus, Morose outlines five essential design principles: size/surface/structure, alternative materials, functionalization, encapsulation, and "reduce the quantity" (2010, 1–4.) Suraud, in an interview study of French nanotechnology researchers, reports that SbD work has moved nanosafety scientists into the nanotechnology industry, redefining the research–innovation relationship (2019, 9–10.) Both Suraud and Kelty (separately) insist that SbD is a culmination of societal concerns to nanotechnology, seeking to resolve a tension, illustrated by Kelty (2009, 2–3) to be enabling nanotechnology as "applications" and mitigating "implications", namely, EHS risk. Kelty (2009, 17) concludes his account of the emergence of SbD as a move from "absolute statements about precaution and danger" to a nuanced "attending to the rank ordering of values taking place"—crudely operationalized under nanotechnology innovation and nanosafety. More recent critiques, such as Schwarz-Plaschg and colleagues, emphasize SbD as a new site for previously "regulatory and political decisions" in the broader "scientization of public policy" that subsumes values to technoscientific practice and expertise (2017, 3.) Van de Poel and Robaey endorse the axiological perspective of Kelty and go further to assert that SbD should—rather than pursue absolute outcomes of safety—be attuned to responsibility in the design process as a preferable facilitator for safer outcomes (2017, 8–9.)

Sub-politics of nanotechnology governance

Sub-politics itself constitutes the third and final dimension of the Beckian framework. Sub-politics is invoked to express the political features evidenced by previous research on nanotechnology governance, rather than the locations of sub-polity or their outcomes in sub-policies. This tertiary tranche of studies can be understood as a response to the question of *how sub-politics are constituted by nanotechnology, and its governance*.

Features of these sub-politics unravel through five genres. First, the format of sub-politics is explored by studies of nanotechnology, nanomaterials and the accompanying moral argumentation. Second are studies presenting controversies and debates, ranging from nanomaterials and nanotechnology, to the proposed need for nanoethics. Various sub-politics of research projects (usually public engagements) are the topic of a third genre. Four, expectations and uncertainty are problematized. This is succeeded fifth by studies reflecting on the role of affect in nanotechnology governance.

Nanotechnology, nanomaterials, and morality

Nanotechnology, across multiple studies, is shown to be replete with sub-politics. One strand of literature centers on this construction in case studies of nanotechnology writ large and applied specifically to nanomaterials. The other strand audits the incipient moral and ethical argumentation, suffused by responsible development, that succeeds and is reflected in nanotechnology governance.

Jotterand (2006, 1), in a reflection, proposes nanotechnology as a "cardinal exemplar" in the "politicization of science and technology", connecting its machinations to the "norm of utility" in applications and wider economic logics. Here, Jotterand describes that "social and ethical issues" associated with the politics of regulation, are "[...] relocated within the public arena which is characterized by competing models of scientific justification and political legitimation" (2006, 4.) In another theoretical piece, Wullweber situates nanotechnology as emblematic of the contemporary "competition state", competing in the "nanotech-race", reduced to an "empty signifier" for actors engaging in a (sub-political) struggle for discursive hegemony (2008, 15–16.) Lindquist and colleagues take note of this discourse—viewed as obsessed with solution framings—to deploy "a problem definition approach" that uncovers a narrow reliance on nanotechnology-as-solution despite ambiguous and malleable problematizations (2010, 13–15.) Again, these "nanotechnology entrepreneurs" operate in a sub-political struggle

for resources (via uptake of problem definitions) coordinated by policy makers. Struggle is seen as critical to the very emergence of nanotechnology as a policy concept in the "politics of taxonomy" of 1990s US government science, according to Eisler, with scientists mediating the politics "between the promissory economy of federal basic science and the industrial economy" (2013, 1.)

Laurent brings the discussion to nanomaterials *per se.* He (2013, 19–20) explains that their ontology as "uncertain objects" affords them with various politics. This is elaborated through three illustrative levels: international (i.e. the aforementioned ISO and OECD) and "science-based", EU "policy-based" and value-laden, and a French experimental approach that could together foster a "democratization of nanotechnology."

Sub-politics in nanotechnology is characterized by ambivalence. Swierstra and Rip (2007, 16–17), in a review of its "moral argumentation", declare that ambivalence has no resolution: the "agora model" of "deliberative approaches oriented towards consensus" is orthogonal to the "structure of the situation." Instead, this sub-politics inhabits an "arena model", of actors and interests, "where some win and others lose" that perhaps reach compromise but paradoxically rely upon a deliberative throughput legitimacy inherent to the arena model.[24] Shelley-Egan (2010) returns to ambivalence in an interview study of industry, seeing "strategic games" and legitimacy seeking in the discourse of responsible development. NGOs perform a necessary role, as enumerated by the interviewees, in the fickle "division of moral labor" for addressing the "broader consequences" against the orthodox preoccupation on technoscientific progress (2010, 1,6-7.) A third study, reflecting on ethical implications of nanotechnology, also finds ambivalence amidst a de-politicizing trend to "ethicalization" of governance that performs the above deliberative legitimacy, "open[ing] up to a broad audience" through ethics, that subsequently "move into ill-defined fora such as ethics committees, expert commissions, [and] citizen panels" (Ferrari and Nordmann 2010, 5.) The discourse of responsible development expects everyone to participate, but elides its sub-political decision-making functions (2010, 10.) McCarthy and Kelty (2010, 4, 8–9) contest this functionality in an ethnographic study of scientific entrepreneurship at a university research center, corollary to (Kelty 2009), evincing how insufficient framings of risk and implications led to controversies and sub-politicization in an ambiguous and "simultaneous" context of governance wary of backlash and "fundamental research into

[24] These two models are inspired from ancient Athens (see Swierstra and Rip 2007, 16–17.)

nanotechnology" (cf. Åm 2013.) [25] Apart from the induction of novel organizations like this Center and reflexive nano-EHS research, calls to "responsible nanotechnology" are answered by the sub-policy of SbD: ultimately "render[ing] the problem into something that scientists can pursue in labs, funders can fund, corporations can implement, and activists can monitor" and alleviating ambivalence (McCarthy and Kelty 2010, 5, 8–9.)

Controversies and Debates

Sub-politics in nanotechnology have previously been depicted in the forms of several controversies and debates. Explicit controversies regarding nanomaterials and nanotechnology, or the perceptual risk and imagined backlash, are recounted. Debating nanotechnology constitutes another strand in the problematization of pursuing and bounding the field of nanotechnology, on the one hand, while debating the scope of nanoethics to evaluate this field, forms another.

The **research context** has summarized the perceived risk (to wit, 'nanophobia-phobia') of laypeople to reject nanotechnology ('nanophobia'), in other words, a *backlash* reiterating the trend of techno-tragedies like GMOs (see again Rip 2006.) The use of nanoscale metal oxides (i.e. titanium, zinc) in consumer sunscreen served as a trial case for this backlash. NGO reports (specifically Friends of the Earth Australia) had suggested toxicity by deploying what Berube (2008, 2–3) terms "risk-profile shifts", in a document study, that can misconstrue scientific findings (see Wright 2016), potentially to galvanize news media attention and bolster "EHS debates over nanoparticles" at the expense of scientists' desired interpretations. In this way, the credibility of NGOs to relay scientific information—by scientists—is jeopardized, a role posited earlier for these third parties (e.g. Bowman and Hodge 2010.) Instead of this realist approach with sunscreen safety, Boholm and colleagues (2015, 14–15) examine various Swedish stakeholder documents (including NGOs and news media) considering another toxicity controversy regarding nano-silver, finding relativist constructions of nano-silver as both "risk object" and "object at risk." Hansen and Baun also review nano-silver, albeit from a regulatory perspective, excoriating the "paralysis by analysis" of an ineffective (sub-political) science—regulation relationship that obstructs decision-making (2012, 2.)

The most documented nanotechnology controversy comes from France—stemming not from nanomaterial toxicity, but the contestation of democracy. Joly and Kaufmann

[25] CBEN, the Center for Biological and Environmental Nanotechnology, later divided into the International Council on Nanotechnology, was associated with Rice University in the US, where Smalley was a professor. Smalley and the Rice University context have been crucial to the emergence of nanotechnology (see also Mody 2010.)

(2008) reflect on a consultancy experience, where they were hired by the municipality to conduct public engagement at the "nanodistrict" in Grenoble. While their advice for a consensus conference was repudiated, the sub-political episode is depicted to emphasize a power-laden arena of different political actors (parties) and stakeholders (NGOs, activists) with little interest from policy-makers in connecting an engagement to decision-making: either to "foster acceptance of the nanotechnology projects", or as a "strategic tool designed to overcome contestation" according to activists (2008, 17–20.) Laurent, in *Democratic Experiments,* offers a broader context to the Grenoble controversy after Joly and Kaufmann's failed consultancy, as a matter of sub-politicizing the "global nanotechnology program" (that is to say, technoscientific capitalism through nanotechnology) starting from the technocratic "Grenoble model" of innovation (2017, 153–54, 159.) The Grenoble case, for Laurent (2017), becomes an opening into two disparate visions of sub-politicization and sub-polities to govern (nanotechnology), with the "mobilizing within" of VivAgora (NGO) opposed to the "mobilizing against" of PMO (activists.) This is reminiscent of Wehling's (cf. 2012) invited *contra* uninvited distinction for public engagement.[26] These controversies, both from the municipal (e.g. Grenoble) and national level (France), are reflected upon by Bensaude-Vincent (2021, 2, 5, 8, 10), who distinguishes a paradigm shift from the 2000s "nano backlash" and co-productionist ideal of public engagement, to the 2010s de-politicizing "public indifference", with an establishment of co-learning stakeholder fora (such as NanoRESP) focused on a "*monitoring model* [original emphasis]" of "risk and toxicity", precluding NGOs, citizens and "democratization." [27] Bensaude-Vincent (2021, 10–11) ends by asserting the official routines and accoutrements of non-policy in NanoRESP that indicate a triumph of stakeholder fora. These fora are explicitly compared to the German NanoKommission accounted for earlier under **stakeholder dialogs and workshops** (see again e.g. Pfersdorf 2012.)

Whereas nanotechnology development has at times been controversial, it is consistently portrayed as a debate contesting the future (see Arnall and Parr 2005), encompassing both politics and sub-politics. Wilsdon (2004, 2) suggests three elements to the debate: (1) imagination, (2) regulation and (3) participation.

On imagination, nanotechnology is debated between "radically differing visions" of the future, with "nano-radicals" pitted against "nano-realists" and "nano-sceptics" (Wilsdon 2004, 2–4.) Part of the nano-radicals' imagination is a movement to human

[26] PMO is short for "Pièces et Main d'Oeuvre"; in English this translates to "Parts and Labor" (Laurent 2017, 156.)
[27] Bensaude-Vincent is a philosopher of science and also former president of VivAgora (2021, 2), at the same time of Laurent's fieldwork (2017, 23–24.)

enhancement and posthumanism, as detailed by Milburn (2010, 1–18) in terms of a singular "nanovision." In Sparrow's (2007, 2–6) analysis of promoters' "rhetorical contradictions" in the debate, this dimension unfolds as a "revolutionary and familiar" narrative, with nanotechnology as both exceptional and merely incremental. On regulation, Sparrow determines an "inevitable and precarious" narrative, where nanotechnology symbolizes "technological progress", incapable of regulatory constraint, yet constantly in need of public investment to basic science (2007, 6–10.) One element is questioned by Hess' US history of nano-EHS mobilization: "is the public interest best represented by rapid commercialization followed by a catch-up period of EHS research and regulation, or is it best represented by a more precautionary approach?" (2010, 24), making the regulation dimension largely a matter of not if, but *when.* Wilsdon (2004, 4–5) adds in the matter of *how* in articulating the debate between poles of continuity (indicating the application of presiding regulatory apparatus) and novelty (indicating the need for new approaches.) This is a rephrasing of the earlier conditions generative of **the governance turn in risk regulation,** whose common claims are dissected by Malloy (2011, 6–7) to propose "an iterative approach to regulation" that formalizes sub-policies like best practices, iteratively adopting more quantitative tools as science develops (against self-regulation.) On participation, Wilsdon (2004, 6) refers to the issue of (again) how and when to involve citizens in order to understand societal implications, before potentially repeating the public disavowal to techno-tragedies like GMOs (cf. Wilsdon and Willis 2004.) Wood and colleagues' (2008, 2) assessment of the debate disrupts this pattern in insisting on a "social science agenda for nanotechnology" that transcends the regulatory ("potential risks of toxicity") and participatory ("social and ethical implications") dimensions to research its imagination—the very creation and oft occluded alternatives.

Previous studies have proposed resolutions–if not modest ways forward–to the nanotechnology debate. For Arnall and Parr, a "social constitution" approach is "crucial", one that relocates the debate from "long-term technical possibilities and ramifications" to "present-day developments" with genuine public engagements (and continued sub-politics) at the fore (2005, 12–14.) For Sparrow, the "rhetorical contradictions" elucidate extant politicization and sub-politicization that convey the debate as a "political struggle to control our own future", one *with or without* nanotechnology. For Hess (2010, 24–26), nanotechnology exhibits political conceptualizations of done versus "undone science", with nano-EHS left comparatively undone and channeled into a scientized "regulatory politics", divided into policies of increased nano-EHS funding and sub-policies of "industrial guidelines" cataloged earlier, that foreclose a more absolute moratorium (see ETC Group 2003.) Hess' emphasis on "scientization" and expertization hence is comparable to Bensaude-

Vincent's (2021) above stakeholder fora and Ferrari and Nordmann's (2010) "ethicalization." For Grunwald (2014, 199–202), the compromise settlement on responsibility, operationalized *inter alia* by the earlier EC Code of Conduct and later RRI, is another manifestation of nanotechnology sub-policy. Responsibility is promulgated across, and to facilitate, research and innovation in these instances of pervasive uncertainty (see also Shelley-Egan and Bowman 2018.)

The imagination dimension in the debate, of competing visions, is enumerated further in the formal Drexler–Smalley debate. In Bueno's analysis, the 2003 debate between Drexler and Smalley about the possibility of nano-scale molecular assembly, turns on the "incommensurability" between a mechanical (Drexler) and chemical (Smalley) approach, suggesting a greater focus on instruments to move it forward.[28] As the paramount "nano-radical" in Wilsdon's above account, Drexler's vision is predicated upon such molecular assembly to rebuild society from the literal bottom up, but with this assembly comes the novel risk of the "gray goo" scenario (according to Drexler), which is itself a risk to investments in nanotechnology that worries the "nano-realists" like Smalley (Wilsdon 2004, 2–4.) To Drexler and Smalley, the debate aims sub-politically to define and "bound" nanotechnology, whose vision is judged feasible and responsible. Yet Kaplan and Radin's study of the enrolled and enrolling "para-scientific media" publishing their correspondence stresses the episode as a choreography designed to manufacture two unambiguous, polarized standpoints from an "ambiguous set of uncertainties" that discursively legitimize scientific uncertainty (2011, 1–2.) [29] They emphasize McCarthy and Kelty's (2010, 23) point that defining nanotechnology reflexively and simultaneously includes its responsible development–in practical terms, excluding Drexler–ultimately joining the call for Wood's (2008) "agenda" on the constitution and context of these "conditions of possibility" (Kaplan and Radin 2011, 22; see also Åm 2019, 1.)

A parallel debate on "nano-ethics", that is, the potential need to include ethics of technology in nanotechnology, connects Wilsdon's imagination and participation dimensions as sub-political self-regulation. Nano-ethics, on the one hand, is contested by the *novelty* issue, while exemplifying the need for broader (ethics) engagement in nanotechnology. Grunwald (2005, 1), in an early effort, concludes on the utility of ethics, but without any fundamental novelty—a position later clarified in Swierstra and Rip's "nano-ethics as NEST ethics", or new and emerging science and technology (2007,

[28] The debate is subject to further critiques from a philosophy of science perspective (e.g. Bensaude-Vincent 2006; Broadhead and Howard 2011.)
[29] Consult Kaplan and Radin's study (2011) for a detailed reference list of the correspondence in *Chemical & Engineering News*.

1.) Against suggestions to declare primitive nanomaterials as a solely technical issue, Kermisch dissects its imagined development stages to assert the need for ethical consideration "already from the simplest kind of engineered nanoproducts" through to "rather sophisticated nanotechnologies" (2012, 1.) The other hand, captured by Nordmann's critique (2007), revolves around the limited ethical attention, censuring proponents of the "speculative nanoethics" tradition for foregrounding wildly *speculative* visions, generative of the nanophobia highlighted in **research context.** This tradition is crystalized, for example, in the Drexler-Smalley debate, at the expense of an ethics of already existing nanotechnology. In Wilsdon's appraisal, this can be read as privileging the (futuristic) imagination debate over the more present regulation and participation dimensions, which is responded to in the research call of Wood et al. (2008.) Analyses by Ferrari and Grunwald attempt to separately resolve the debate, with Ferrari (2010, 1) asking for a "metaphysical research program" to deepen the limited ethical approaches (risk-benefit consequentialism and value based deontology), and Grunwald (2010, 2) delineating between extant "applied nano-ethics" and a speculative "explorative nanophilosophy" that "prepare[s] the ground for future debates." In either case, on novelty and speculation, scientists propose sub-policies of self-regulation to resolve the sub-politics.

Interrogating research projects and outcomes

Sub-politics of nanotechnology governance, as elaborated above, arise in the more unceremonious context of research projects—particularly public engagements. In their own literature survey, Delgado and colleagues (2011, 5–11, 15) describe a series of five prominent sub-political "tensions", between theoretical ideals and practical compromise, as "why should public engagement be done", "who should be included", "how should [it] be initiated", "when is the right time" and "where should [it] be grounded"—proposing greater reflexivity and anticipation as "alternative routes through the landscape." Highlighted findings from these projects are below reported geographically from Australia, the US and the UK.

Lyons and Whelan scrutinize Australian state-sponsored public engagements. They identify de-politicizing limitations of "a conflict of interest" by a government committed to developing while still regulating nanotechnology, "closing down dialogue" with engagements constructed on settled issues, "denying dissent" in favoring industry over NGO participation, and disconnection from policy-making processes "with little options to actually change engagement processes or their outcomes" (2010, 5–10.) They finish with a series of seven recommendations to formally institutionalize engagements into government with independent auditing and without conflicted agencies that imply

a preference to re-politicize the engagement and de-politicize the institutionalization (2010, 11–12.) Similarly, Petersen and Bowman (2012, 11–12) focus on the "discourse of public engagement" via 14 Australian stakeholders, urging institutionalization, politicization and "reframing" of the public involved from technical issues to the "science-based economy and culture" nanotechnology is claimed to provide.

Turning to the US, the "NanoFutures" project offers two reflections on public engagement. First, Selin (2011, 4–5) explains the project as turning from speculation to "plausible visions" through a sub-political process of "development" of scenes, "vetting" of technical plausibility and "deliberation" of the scenes by broad stakeholders, as a tool for anticipatory governance. Second, Davies and Selin (2012, 14–15) present five tensions 'in the engagement evincing "messiness" that could be addressed by "innovation in methodology and practice." [30]

For the UK, Grieger and colleagues (2012) alternately explore the embedding of public engagement into risk governance, revisiting the UK "Nanodialogues" project exploring nanoparticles for environmental remediation. They conclude (2012, 12–13) that engagements on tangible cases and "where ambiguities and uncertainties are high" can help inform actual decision-making and penetrate the scientized boundaries of risk assessment (cf. Hess 2010.)

Expectations and uncertainty

Expectations and uncertainty refer to temporal aspects at work during and after sub-politics. On expectations, Selin (2007, 19–20) recounts the "emergence of nanotechnology" as a convergence between science and politics over competing future expectations, with the future a "legitimating discourse" ensuring incipient development. Hence the visions behind the above Drexler–Smalley debate are essential to nanotechnology, before they become "too loaded" and amenable to sub-politicization (cf. Kaplan and Radin 2011.) Turning to constituting expectations, Alvial-Palavicino and Konrad spotlight the nanomaterial graphene in a mixed method interview study, revealing "anticipatory practices" of "circulation of promises", "roadmapping" and "calculative practices" shaping expectations in three sub-polities, "high profile science publishing", "European public funding" and "the emerging technologies market", yielding the performative effect of "structuring spaces within the field" (2019, 9–10.)

[30] For an introduction to anticipatory governance, see (Barben et al. 2008.)

A second group of studies problematize the uncertainty and its sub-political qualities, so conducive of the above expectations. Ebeling (2008, 22–23) investigates this latter market component, in an ethnographic interview study of "mediating uncertainty" in nanotechnology "definitional struggles." The study shows an expert preoccupation with controlling the prevailing "perceptual risks", as defined by a 2005 Lux Research report (qtd. in Ebeling 2008, 19–20), jeopardizing investment through sub-policies of alienating scientization. In this way, Groves seeks to theorize uncertainty in nanotechnology. Groves (2009, 13–14) first questions the reliance on risk to depoliticize a "landscape of uncertainty", mapping instead various "modes of contingency" to advise for a holistic approach allowing for sub-politics between these modes.[31] In another account, Groves applies a "politics of uncertainty" lens to revisit 2000s UK nanotechnology public engagement. The study describes two narratives of "restoring trust" (enabling a return to risk approaches) and "building robustness" (enabling "reciprocal commitments around agreed values and priorities between social actors") domesticating uncertainty, with the former favored in sampled policy documents, that serves to legitimate future-oriented policies in the present (2011, 10.) This overwhelming rationale to mitigate uncertainty (as reported by Ebeling and Groves) is furthermore visible in a Flemish research project to bolster (nano)scientist reflexivity. They demarcate uncertainty into three sub-policy pillars of "strategic uncertainty" about the future, "complexity" about the science, and "ambivalence" by the wider public on value mobilization (Goorden et al. 2008, 2–5.)

Affect

Affect, as a genre of sub-politics, is seen as a central component by policy-makers to anticipatory governance, especially nanotechnology with its future orientation. This is where the context of risk society in the **research context** intersects the expert tendency to perceptual risk driving uncertainty mitigation as discussed above. Two studies, in particular, underscore the salience of this affective governance.

Kearnes and Wynne (2007, 1), in another review of UK nanotechnology public engagement, background the governance turn in the manifestation of a perceived "legitimacy crisis" in government and policy, after the techno-tragedies. Rather than directly problematizing uncertainty, the problem is framed in terms of "public ambivalence as a nested set of enthusiasms and anxieties", with policy-makers mandating "rational enthusiasm" operationalized into sub-polities of public engagement

[31] These modes (Groves 2009, 7–13) are divided in two ways: an insider perspective (modes of risk, uncertainty, ignorance and nescience) and an outsider perspective (modes of indeterminacy, trust, decision horizons, commitments and values.)

as the solution to produce legitimacy (and trust.) Kearnes and Wynne then conclude by proposing a counter-project with public ambivalence staged as a "creative resource" to address the dearth of public value mobilization and absence of contextual power relations (an assessment broadly shared by the **nanotechnology, nanomaterials and morality** genre) in public engagements (2007, 10–11.) Enthusiasm and anxiety, as affect, is shown by Anderson's (2007) essay on anticipatory governance to have sub-political effects through an affective legitimacy regarding the future. An affective disposition of hope and optimism, akin to the rational enthusiasm examined by Kearnes and Wynne (2007), travels between (future) nanotechnology and constant, presentist decision-making in the "assumption that contemporary governance works through and modulates affects" including the above sub-politics of expectations and uncertainty (2007, 4.) Hope and optimism, according to Anderson (2007, 6), then *effectively become* sub-policies, "[...] measured, named and monitored through a range of statistical techniques and qualitative methodologies" to legitimate funding and manage perceptual risk against fear or anxiety.

Conclusion: emphasis and underemphasis

Previous research has clearly shown areas of emphasis and underemphasis on nanotechnology governance. Under sub-polities, the research has focused primarily on conducting and reporting on novel public engagements. The organizational role of newer third-party organizations is relatively underemphasized. Under sub-policies, studies on standards and standardization have been prioritized, in contrast to information and coordination tools. Under sub-politics, the quotidian structure of governance that articulates conditions of sub-politics is less emphasized than the many studies of controversies and debates around nanotechnology.

FIVE/ **METHODS**

The methods for this thesis combine theoretical, which do not generate new data, and empirical research work. Of the five appended papers, two are thus theoretical, while the rest are empirical, as shown below in **Table 5**. These empirical papers relate to three individual studies. Preparations for the theoretical papers are briefly summarized first, followed by the empirical studies. This section concludes through recounting some reflections on reflexivity in working as an embedded social scientist in the Mistra Environmental Nanosafety (research) program.

Table 5. Relation of appended papers to empirical studies

Paper	Study
Paper I	Theoretical;
Paper II	no empirical data
Paper III	Study A
Paper IV	Study B
Paper V	Study C

Theoretical papers

Papers I and II are theoretical papers in that they do not use empirical material and instead offer theoretical contributions as syntheses (detailed further in the subsequent **summary of appended papers.**) All papers are unique, in other words, they have disparate conceptualizations and do not share empirical material.

Paper I is written as a review essay of Habermas' monograph (1975), *Legitimation Crisis.* The intention is to review that work from the perspective of contemporary research in economic sociology, classical political economy, science policy (to steer the economy), and a nascent specialization of STS that can be termed political economy of research and innovation. However, there is no systematic literature review—only a theoretical exploration. Literature is presented here to exemplify arguments from these fields to explore the contours of research and innovation as a key economic sector to be managed by the state.

Paper II constitutes another theoretical exploration, albeit mostly within the specialization of responsible innovation. The concept is to critically discuss this scholarship, articulating a series of discomforts in the interim, while sourcing deeper theoretical understandings and other research suggesting ways to advocate for the presumed objectives of responsible innovation that culminate in corollary commitments. The discomforts are inspired by the "politics of discomfort" operationalized by "affective methodologies" in the usage of Chadwick (2021, 3–4.) More than a review, the exploration is intended as a 'manifesto' addressing the scholarly community and ourselves as members. Most of the critique is sourced from the RRI journal of record and target audience, the *Journal of Responsible Innovation,* with explanations and ways forward outside of the journal (in general, from STS.)

Paper II was written collaboratively amongst a reflexive group of early career researchers (ECRs) during the Coronavirus pandemic and in the context of declining funding importance (and rising anxiety) for European researchers on RRI. This is the end of the Horizon 2020 FP from the European Commission, which is referred to in Paper II as the "horizon of RRI." In the beginning, observations and frustrations were shared from collective experiences. Thereafter, colleagues were consulted on the draft or asked to provide some information later used to substantiate our argument.

Empirical studies

The methods behind the empirical studies, correlating with three appended papers, are reviewed below. Study A is a systematic stakeholder analysis of European nanotechnology development. Study B is an argument mapping of a regulatory controversy regarding carbon nanotubes. Study C uses a series of semi-structured expert interviews on chemical substitution and SSbD. Key details from the studies are extracted into **Table 6**, on page 61.

Study A: Systematic stakeholder analysis

Study A is the result of a mixed methods (quantitative and qualitative) approach which aims to map the recent European landscape for emblematic domains of nanotechnology development. The output is equivalent to Paper III. Study A uses public data regarding both scientific journal articles and technology patents to identify European stakeholders, analyze their distribution, categorize their constellation and ultimately reveal the geopolitical spread. Earlier steps proceed from quantitative bibliometric and patent analysis to mixed stakeholder analysis.

The stakeholder analysis identifies the 100 top stakeholders in each domain, as determined by most numerous journal article and patent activity. For simplicity, Paper III lists only the top 10 in the article itself. No patent search is applied to the domain of environmental nanosafety. Stakeholders are created in three ways, from the metadata associated with the journal articles (publishing institutions and funding organizations) and patents (applicants), by filtering through the results of keyword searches on online databases. Journal article data are culled from Scopus; patent data are used from Espacenet, maintained by the European Patent Office.

These searches result from reviewing the literature on bibliometrics (e.g. Huang, Notten, and Rasters 2011) and patent analysis for nanotechnology (e.g. Jürgens and Herrero-Solana 2017)—with dual methodological objectives. One, Study A examines generalized nanotechnology, certain nanomaterials and environmental nanosafety research. Nanotechnology, especially, is reduced to a small but representative keyword sample. Two, the search strings are kept similar between journal article and patent databases to maximize comparability. Robustness for the search strings is evaluated by manually reviewing the most cited or relevant journal articles and patents; this ensures, for instance, that a journal article from the carbon nanotube search is indeed carbon nanotube research.

This stakeholder analysis is thus systematic in selecting the most prolific patent applicant, academic institution and funding organization sources from these domains, rather than applying a qualitative or local sampling approach. Stakeholders, here in Paper III, are considered to be impacting and influencing "[...] the evolving nano-race in Europe as presented by research and innovation activity in the four cases", as outlined by the stakeholder analysis method (Engi and Glicken 1995.) The key delimitation here is "research and innovation activity", instead of all potential issues in recent European nanotechnology that would imply a wider stake.

Study A examines both the presence and type of stakeholder. First, it identifies 367 unique stakeholders across the four domains. Each domain and stakeholder source evince substantial concentration in the shares of journal articles and patents, that is, the most prolific stakeholders are attached to a larger share than the others. Second, stakeholders are moreover classified by a taxonomy which was created by researching their organizational status. This step is essentially qualitative, given the multiple potential taxonomies or rationales behind the classifications employed. The taxonomy is based around four sectors of government, academia, industry and private individuals.

While stakeholders are central to Study A, the method is cross-referenced to the associated countries active in the nano-race in consideration of the existing discourse and public sector support. Each stakeholder is coded to the residing country, assisted by online searching, and to the European Union for EU level funding organizations and initiatives (for example, directorates general and framework programs.)

In relying upon stakeholder analysis, the nano-race discourse is extended from a focus on public funding or national and supra-national policy mechanisms to more multifarious and nuanced stakeholders. It allows for a systematic investigation beyond the most powerful, or renown, stakeholders. Through aggregating bibliometric and patent analysis with stakeholder analysis, the stakeholder power dynamics implicit in science and technology development are foregrounded. The political economic context to this development is thus elaborated, which helps to understand the concurrent nano-race.

Study B: Argument mapping

Study B, comprising Paper IV, proceeds to another kind of mapping, surrounding the specific Study A domain of the nanomaterial carbon nanotubes. This study seeks to map the regulatory controversy of carbon nanotubes anticipated by its placement on the Substitute-It-Now (SIN) List, published by the Swedish NGO ChemSec (see Lennquist et al. 2024) that is unaffiliated with any actual regulatory procedure.[32] The controversy emerged—not amongst regulators—but with engaged scientists responding to publication of the decision in the journal *Nature Nanotechnology* (Hansen and Lennquist 2020), as a debate on the topic of substitution (namely, the replacement of carbon nanotubes with alternative materials.) To complete this mapping, Study B consists of a literature review, content analysis and argument map.

The study is based on empirical, scientific source material containing arguments regarding the normative status of carbon nanotubes in how they should be used. Given both their prolific nature in the historical development of nanotechnology and the volume of empirical sources, a systematic literature review is undertaken. This literature review uses Scopus, again, to find any potential sources with normative arguments restricted to carbon nanotubes, and exclusive of other nanomaterials or nanotechnology as a discourse. From an initial population of 325 results, ten articles are culled for analysis.

[32] ChemSec is an NGO based in Gothenburg, Sweden. The NGO offers other services to clients, like the chemicals industry, beyond just SIN. The overriding aim is to bolster "the change to safer chemicals." https://chemsec.org/about-us/

Seven candidate articles are ultimately selected for a content analysis, including those from the *Nature Nanotechnology* debate. These candidates are analyzed to unravel any relevant argumentation and their relation to other scientific results as evidence. Hence their normative content on the use of carbon nanotubes is the object of analysis, instead of more general thematic or discursive approaches. The content analysis is then transformed into intertextual analysis, which interpolates the argumentation across the candidate sample, through the aid of visual mind-maps.

Argument and value maps serve as the final empirical product of Study B. The corpus includes six of the above seven articles, five of which come from the original debate. As a method, argument mapping is applied in a simplified manner from (Sharkey and Gillam 2010), who interrogate the issue of healthcare prioritization with the instruments of "argument", "counter-argument" and explanatory "reason(s)." The argument mapping in Study B is instead oriented to a set of two opposing *pro-* and *contra-* camps, presented in a series of three *pro-* and six *contra-* arguments. Counter-arguments are mentioned in Paper IV as implicit rhetorical relationships due to the inductive approach and informal nature of the forum. Some of the arguments are specific to a single article or are not related to others. Moreover, the corpus spans beyond the debate period, without explicit references to the earlier articles. This method augments the ostensible debate by emphasizing both its normative (as opposed to technical) characteristics and its persistence prior to the controversy.

The argument mapping is analyzed and coded through a series of three end values—in short, values to protect *per se*. End values, while mutually exclusive, reside across the two camps, with the implication that some opposing arguments could be suitable to reconciliation. This subsequent exploration displays the utility of titular "implicit values" in understanding mobilizing factors underneath the issue of carbon nanotube substitution. By invocating values, the often disparate argumentation in the corpus is clarified and contextualized.

Study C: Semi-structured expert interviews

Study C stems from the above interest in carbon nanotubes explored throughout the initial studies. Instead of the nano-race or regulatory controversies examined by Studies A and B, Study C turns to the organization behind the SIN List, namely ChemSec, and questions of fostering innovation via (chemical) substitution. This study thus problematizes practices of substitution—itself a component of chemicals management—towards greater environmental safety and sustainability. To do so, it intends to

accomplish five objectives: (1) to describe the role of ChemSec in this broad field, (2) to map out representative uses of the SIN List, (3) to capture views on the List's defining predictive claims, and in parallel, (4) to understand the perceived relation between substitution and innovation, as well as (5) perceived distributions of responsibility and regulation. These final two tasks are inspired by the emerging EC framework (2022) on SSbD,[33] rather than ChemSec.[34]

These objectives, unlike Studies A and B, form multiple potential papers. For objectives 1 and 3, there is Paper V appended to this thesis. While objective 2 is summarized as background for Paper V, a full account is outside the thesis scope as a continuing project. Furthermore, objectives 4 and 5 regarding SSbD are ongoing, but not included in the thesis. The topic of SSbD is broached during early interviews and are incorporated into later sessions. The tasks are accomplished through a semi-structured expert interview format that proceeds from steps of interview strategizing, purposive and snowball sampling of stakeholders, accumulating interview material, which, put together, results in combined theoretical and thematic analyses.

Regarding strategy, Study C is iterative and interviewee dependent, containing three facets: backgrounding, observation and interview sessions. In order to determine a research design, phase one utilizes background interviews to better navigate this context. These are conducted with experts adjacent to the research network for accessibility and are centered around a ChemSec employee. Simultaneously, for phase two, this network—projecting from ChemSec—was followed through its online self-presentation and close observation of their webinar series from June 2023 to January 2025. The purpose of the observation phase is to understand ChemSec messaging, external cooperation, and its core issues.[35] The core interviews are the third facet. The interview criteria expands from seeking active SIN List users (i.e. professionals), first to general stakeholders (aware of the SIN List and ChemSec) with an interest in substitution, and second to those also aware of SSbD. This initial criterion was prohibitively restrictive and time-consuming, such that later iterations presume less direct knowledge of the SIN

[33] In this thesis, SSbD will refer to the work of the Commission through the Joint Research Center (i.e. Caldeira et al. 2022; Caldeira et al. 2022; Caldeira et al. 2023.) Alternative frameworks or general guidance, while outside this official work, are available to apply SSbD in practice (e.g. Cefic 2024.)
[34] The motivations of ChemSec and remit of SSbD do coincide, and this animates the combined focus of Study C. Firstly, ChemSec tools like the SIN List are mentioned in the reports (e.g. Caldeira et al. 2022, 44.) Secondly, ChemSec is implicitly referred to in acknowledging "the following external experts for their collaboration and input" (Caldeira et al. 2023, 2), with reference to a ChemSec expert.
[35] ChemSec webinars are archived here: https://chemsec.org/news/?keyword=31. It maintains a presence on social media and has a YouTube channel with generally satirical videos, available from: https://www.youtube.com/user/ChemSec.

List. There are ultimately two, ideally overlapping, stakeholder samples of (1) SIN List aware and (2) SSbD aware interviewees.

Stakeholder sampling originates from a purposive approach, which becomes more contingent (i.e. snowball sampling) over time. The purposive sampling proceeds from three populations. One, research network contacts are asked either for an interview or other suggested experts. Two, contributors to ChemSec webinars and especially businesses participating in the ChemSec Business Group are selected.[36] Three, identifiable organizations from the recent EC PFAS restriction proposal are added to the sampling, upon recommendation of an interviewee.[37] Final interviewees are asked for additional contacts, which has garnered some snowballed interviews. The explicit support of ChemSec is not part of the sampling process to protect the neutrality of interviews. Sampling concludes based on the demarcation of repetitive findings and a balance of stakeholder type.

The final sample represents diverse stakeholder types. Study C prioritizes organizations making business decisions surrounding substitution or SSbD. These are grouped as large companies, small and medium enterprises (SMEs), and adjacent technical consultants. Public municipalities are added, with their public obligations and procurement capacities. Regulatory agencies are additionally sampled to learn about regulatory development (specifically SSbD), compliance procedures, and experiences (or perceptions) with the above types. Lastly, environmental NGOs and other academic experts are incorporated for context and perspectives on perceived economic behavior.

Interviews involve five or six different modules.[38] Sessions begin with background questions on work environment, job duties, and interviewee biography. Next, interviewee awareness of ChemSec is investigated, followed by their awareness of the SIN List and its claim to anticipate future regulatory development. These two modules are fundamental to Paper V. Then, this knowledge is juxtaposed to familiarity with regulations and advanced material classes, especially nanomaterials. Questions are

[36] The Business Group consists of member organizations and ChemSec to discuss the business context of working towards greater chemical safety and sustainability, and to meet other professionals and organizations. These members have been referenced in ChemSec webinars or in promotional materials. A ChemSec prospectus is available here: https://chemsec.org/reports/chemsec-business-group-folder/.
[37] The PFAS chemical group (Per- and polyfluoroalkyl substances) is under consideration for restriction under the REACH legislation. This is a prescient issue for both ChemSec and many interviewees, with a voluntary comment period underway during the sampling period. These comments can be downloaded as a summary index or in full from a European Chemicals Agency (ECHA) webpage: https://echa.europa.eu/comments-submitted-to-date-on-restriction-report-on-pfas.
[38] See Appendix 1 at the end of Paper V.

adapted to the stakeholder role. Moreover, a module to gather perceptions on SSbD is introduced in the final interviews. The semi-structured format is chosen because of the expert context, allowing for the benefits of spontaneous follow-up questions coupled with a series of consistent interview tasks.

Study C includes 35 interviewees, with 35 sessions in total. This yields 35.5 hours of interview material, accumulating from June 2023 to June 2024. The average length is 65.7 minutes. All interviewees reside in Europe or North America, with a concentration in Sweden and Denmark.[39] Ethics and specifically free, prior, informed consent (FPIC), is mentioned in the initial sampling, reiterated during the interview and in subsequent contacts regarding use of interview material for Paper V. All interviewees consent to being an anonymous participant to Study C.

There are two forms of analysis in Study C: thematic and theoretical. Firstly, all interviews are recorded and transcribed. Notes are taken to facilitate recall and reflect on interview mechanics; there are additional written materials shared during or after interviews. Secondly, interview transcripts are imported into NVivo qualitative analysis software for inductive (thematic) coding to organize findings and identify intertextual themes. Thirdly, this thematic analysis is further detailed by theoretical analysis, which proceeds to address study objectives 1 to 3 via deductive (theoretical) coding. Here, the coding is built manually to answer the questions of how and why is the SIN List used, and what is its perceived credibility. This is the empirical base of Paper V.

Expert interviews allow for nuanced and exhaustive answers and general explanations to the topics of Study C. Due to barriers to entry, deriving a larger sample, for instance with surveys, are impractical and would not generate the necessary material. Functions of the SIN List are mentioned in literature reviews (OECD 2023a; for SSbD, see Caldeira et al. 2022) and it has been incorporated into economic analysis of REACH (Coria, Kristiansson, and Gustavsson 2022.) Yet there is no detailed examination of its stakeholder perceptions. SSbD, alternatively, is a nascent framework with current questions as to feasibility and voluntary stakeholder uptake.

[39] Some interview statistics are available from Appendix 2 in Paper V.

Table 6. Overview of study methods

Study	Methods used	Key aspects
Study A	Bibliometric analysis Patent analysis Stakeholder analysis	Four domains of research and innovation: nanotechnology, carbon nanotubes, nano-silver, environmental nanosafety Search databases: Espacenet (patents), Scopus (journal articles) 367 unique stakeholders for study years 2010-18, inclusive Stakeholder sources: patent *applicants*, academic *institutions*, funding *organizations* Stakeholder sectors: government, academia, industry, individuals
Study B	Systematic literature review Content analysis Argument mapping	325 articles found with normative language on carbon nanotubes Final corpus of six articles Five articles from original *Nature Nanotechnology* debate Two camps: *pro-* and *contra-* carbon nanotube substitution Three *pro-* arguments Six *contra-* arguments Three underlying implicit values belonging to the camps
Study C	Interview strategizing Snowball and purposive sampling	Three phases: background interviews, ChemSec observation, interviews Interviewees with a stake in either substitution (SIN List) or SSbD

Semi-structured interviews Theoretical and thematic analysis	Sampling from research network, ChemSec outreach, PFAS restriction commenters, followed by contact suggestions Stakeholder sample from large companies, SMEs, technical consultancies, municipalities, regulatory agencies, academic experts 35 interviewees over 35.5 hours 5-6 session modules Average length: 65.7 minutes Europe and North America Inductive thematic coding of interview material Additional deductive coding on SIN List

Reflections on reflexivity

The empirical milieu of the researcher has guided the design and subsequent studies that predicates the thesis. There are two constitutive facets here. First, this PhD project is situated within, and funded partly through, the interdisciplinary environmental science research program entitled Mistra Environmental Nanosafety. Second, the Mistra program was administered by Lund University, such that Lund became the locus of research activity. Researcher navigation across these facets can be described as exercising reflexive participant observation.

Mistra Environmental Nanosafety ran from 2013 to 2023, with this project tied to Phase II continuing from 2019.[40] Overall, the program sought to explore the environmental risks and regulatory implications of natural and engineered nanomaterials. Based in Denmark and Sweden, natural environmental scientists were paired with regulatory scientists (investigating scientific gaps in compliance and needs for regulation) and a cadre of social scientists. The program was further supported and actively followed by corporate sponsors, notably the packaging conglomerate TetraPak. Program researchers hence belonged to a multi-stakeholder consortium—mobilized for sampling in Study C.

[40] Mistra is the Swedish environmental research council, a public funding agency of the sort exhibited by Study A. More information is available about the Environmental Nanosafety program here: https://environmentalnanosafety.mistraprograms.org/

The program was observed over these years through quotidian notetaking, conferring with the work package, and learning the practice of Environmental Nanosafety. Biannual consortium meetings (and monthly work package meetings) helped to direct the project and develop tacit knowledge about the research. The program also launched an online webinar series (during the pandemic) to communicate research perspectives and findings. These often responded to tangential topics like "Creating Trust in Nanotechnology", "Responsible Innovation in Nanotech", or "Nanomaterial Regulation – A Driver or Barrier for Nanotechnology Innovation?" that, again, helped cultivate a research network instrumental for Study C.[41]

As a participant, some of the studies form deliverables to the Mistra program. Out of six work packages, this project is tied to work package 4.3 on societal and stakeholder implications. The package was envisioned to deploy stakeholder engagement and learning alliances within the consortium, but a personnel change necessitated a turn to different methods. Studies A and B are deliverables to the work package, whereas Study C surpasses the program timeframe. The impetus to Study C is the awareness of ChemSec from Study B and the program's interest in SbD and SSbD. Unrelated to Studies B and C, but attached to the work package, ChemSec participated in an environmental assessment of graphene (see Mumberg et al. 2023.)

Study B is notable as a reflexive deliverable. Most of the analyzed articles are authored from within the Mistra program and the work package. This offered unique access to, and informal reflections from, these authors. What is more, Study B was presented to the consortium (prior to submission) in 2021. The event prompted some debate on the ethics of Environmental Nanosafety yet yielded professional support for the reflexive approach of the work package. No peer review was conducted within the program and the published Paper IV was distributed to the engaged authors.

In an earlier iteration, the thesis was proposed to apply participant observation within the Mistra program. This proposal, and the Corona pandemic, resulted in embedding the researcher with another work package of nanotoxicologists at Lund University. Weekly group meetings and separate biannual symposia, alongside the co-working environment, helped to acquire additional tacit knowledge.

The NanoSafe4All collaborative initiative descends from the Lund administration and wider consortium as another background and node to the research network. It is a

[41] Details about the webinars can be browsed from the program webpage, at: https://environmentalnanosafety.mistraprograms.org/events.html

continuing initiative to bring together aspects of the consortium in the continuing aim of Environmental Nanosafety beyond the Mistra program. One component has been to introduce nanoscience education to Swedish students. The initiative hosts frequent symposia similar to the Mistra program; these have assisted in general networking for Study C.

SIX/ **SUMMARY OF APPENDED PAPERS**

This section briefly introduces the five appended papers to this thesis. Their highlighted findings are summarized, in numerical order. These summaries conclude with their suggested scientific contributions. Methodological elements are presented earlier in the **Methods** section**.**

Paper I

The enabling policy goals of nanotechnology, depicted in the **introduction,** presumes that research and innovation are now a problem for the state. Paper I updates the literature and explores this very settlement—two generations after Habermas' landmark *Legitimation Crisis* (1975) and one generation after Beck's *Risk Society* (1992.) The format of Paper I is a review essay centered on the former monograph.

Central to the endeavor is replacing the commonly used "late capitalism" or "advanced capitalism" (Habermas 1975, 1) with "technoscientific capitalism", attached to a reengagement with Lyotard's original proposed understanding of the term (1984, 45–46.) This reengagement stems from the fledgling research program of a political economy of research and innovation, which envisages technoscientific capitalism as "the increasing co—production of capitalism and technoscience" (Birch 2017, 440; qtd. in Palmås and Surber 2022, 373.) Assetization, as opposed to commodification, is suggested as its prime economic manifestation and consequent research topic (Birch 2020.)

Capitalism, in the Marxian school of thought, is theorized as prone to crisis that can eventually challenge the politico-economic system. Habermas contributes to this longstanding discussion with his dissection of the "Keynesian welfare state" (Lash and Wynne 1992, 8), by outlining a set of crisis tendencies. *Legitimation Crisis* asserts a logic of displacement between crises of rationality, motivation and legitimation; the problem of this 1970s moment was of inadequate political steering of the economy. Some of the critiques leveled at Habermas supposed a retreat of the welfare state, with less license to steer the economy. This can be seen in Beck's dismissal of a "generalized notion of crisis" (1992, 189) set against emerging individualization and the aforementioned "disintegration of institutional power" (Beck 1997a.)

Paper I invokes the case of nanotechnology to embolden the problematization of "promissory legitimacy" (Beckert 2020) as a novel dimension of Habermas' schematic. Here the example is in the "promissory regime" (Beckert 2020, 321) projected onto nanotechnology. This regime depends on the capacity to precipitate *public* research and innovation funding in the present for commercial uses in the future with *private profit gains*—insofar as the policy goals intersect with dynamics of technoscientific capitalism. This promise can either derive legitimacy proportional to its perceived credibility or alternatively spur a legitimacy crisis in its withdrawal. Our argument concludes by positing the likelihood of "political, not economic, collapse" in professing that " [...] the legitimacy of contemporary technoscientific capitalism – and of any future mutations thereof – rests on the promise to offer 'requisite' economic growth while hitting climate targets at an equally 'requisite' rate."

The scientific contributions are twofold. First, research and innovation policies, and policy regimes, are positioned as salient concerns for the fields of economic sociology and classical political economy in the study of capitalist dynamics. Nanotechnology is but one case in point. Second, alongside studies in assetization, the dual problems of legitimacy and crisis tendencies under technoscientific capitalism merit greater attention within the political economy of research and innovation.[42]

Paper II

Paper II moves from the enabling policy goals embedded in nanotechnology to the "horizon" of the RRI paradigm. The motivation is to reflect on the premises of RRI and to evaluate the frequently communicated but contrasting aims of "revolution and evolution" in the European research and innovation policy apparatus. In essence, the logic of RRI is argued as the increasing alignment of science with wider society, or the lay public. The argument unfolds around an explanation of a series of five discomforts and five commitments in the ambition to influence this community of RRI practice.

The first discomfort is "the hype", which combines questions of innovation novelty with the hype necessary to secure our own reflexive positions of power within and as a whole community. Second is "the public(s)", problematized as uninterested and ignorant of the RRI agenda, with little certainty of a convergence to actual public

[42] The political economy of research and innovation (PERI) approach is loosely defined. Similar terms are the political economy of technoscience (Birch 2013), political economy of science (Tyfield 2017) or Marxist studies (Moore 2020) of science and technology, i.e. Marxist STS (cf. Hamlin 2007.) A specialization has been proposed as a cultural political economy of research and innovation (Tyfield 2012.)

values. Third is "the bubble" of the RRI community itself, one that we find to be increasingly esoteric and impregnable for outside scholars. Fourth is "the politics", presented as inadequate due to the predominant roles of scholars and policy-makers and moreover preoccupied with utilizing society as a democratic legitimacy reserve. Fifth is "the message", in the sense of disconnected RRI outputs emblematic of the research and innovation *status quo.*

Regarding the five commitments, we pledge first to "challenge our assumptions", which include both innovation and society and to try new forms of practice. A second commitment is to "think about the mechanics of change" in pursuing greater "institutional entrepreneurship" to change the research and innovation apparatus from within. Third is to "expand our horizons" in thinking of methods entirely outside of the apparatus and stimulating discussion back within the community. A fourth commitment describes ways for this community to act, namely, "to foster cooperation and care" rather than remain imprisoned in "the bubble." The fifth commitment concludes to "keep calm and carry on" in terms of focusing less on the state of RRI and more on the fundamental premises it tries to rectify.

Paper II is published as a discussion forum with the *Journal of Responsible Innovation.* There are consequently three replies to our 'manifesto', in Coenen (2022), de Saille (2022), and van den Hoven (2022.) Paper II contributes to the literature on RRI, within broader scholarship on responsible innovation. It can also be understood as a pragmatist critique of RRI (see Cohen and Gianni 2023, 3–4.) By critiquing the apparatus of RRI, Paper II can inform future discussions on policy-making and evaluation in policy studies.

Paper III

Instead of pursuing the alignment of science with society, Paper III begins to question the constitution of the *status quo* research and innovation governed by a larger policy apparatus. These are not questions of including broader society, but of the more narrow "responsible development" (European Commission 2004), including economic development, in contrast to more recent emphases on responsible innovation of nanotechnology. This is done through revisiting a frame of geopolitical and geoeconomic contestation through a so-called "nano race." More research and innovation, as a proxy to economic development, has been promised as a way to fuel the engine of economic growth in future commercial uses (outlined in the **introduction.)** The political economy of nanotechnology therefore plays an important role in either enabling or constraining nanotechnology development.

Paper III utilizes the nano race framing as a background to evaluate, by means of illustrative cases, a recent snapshot of responsible development. Responsible development is interpreted as preserving principles in innovation, as in, precaution, safety and responsibility. As envisioned, it could result in an empirical movement away, i.e. substitution, from the most concerning nanomaterials, in addition to an economic development towards entrepreneurial technoscientific capitalism. These nanomaterials are not synonymous for greatest hazard, but rather selected for both their technological maturity, scientific evidence of hazards, and the scientific communication of the findings. This question is contrasted with a larger, generic race of nanotechnology and an opposing race within nanosafety research.

Results are designated on two levels: (1) the *who* of nanotechnology stakeholders across four domains and (2) the *where* of associated countries and stakeholder groupings. Both are delimited to the years 2010-2018 and applied to Europe. Specifically, the four domains are nanotechnology, the nanomaterials carbon nanotubes and nano-silver, and environmental nanosafety research. The revealed nanotechnology development shows both concentration in stakeholder research and innovation output and similarities between the first three domains (minus nanosafety) in a non-decrease of patents and journal articles. This provides little support to the above substitution hypothesis. Distributions of countries and stakeholders tend towards concentration amongst the economically hegemonic nations and repetition of a small group of key stakeholders (also against entrepreneurship.) Stakeholders from patents predominate in academia and the private sector, institutions tied to journal articles tend towards academic and public sector stakeholders, whereas funding organizations are comprised mostly of the public sector. One key exception is the domain of environmental nanosafety, with a divergent array of countries and stakeholders, that suggests a segregated responsible development through specialization rather than reflexive, SbD nanotechnology.

There are three scientific contributions from Paper III. First, the nano race framing for nanotechnology is updated for Europe, with an extensive stakeholder inventory. This framing is adapted to the methods of stakeholder analysis, providing resources for future studies. Second, the problematization of safety in responsible nanotechnology development builds on substitution and precaution as understudied pathways to achieve RRI. Third, Paper III argues for an interrogation of (geo)political economy in the multifaceted conversation on safety and sustainability. The results indicate maturing nanomaterials merit continued research, in lieu of implementing SSbD approaches for just the most speculative innovation processes or most novel materials.

Paper IV

Carbon nanotubes, one of the domains from Paper III and the subject of Paper IV, are a signal achievement of early efforts to both realize nanotechnology and manufacture for commercial use (see Mody 2010.) They are also a concerning nanomaterial, in terms of safety, which raises questions about their use. Paper IV posits that carbon nanotubes present an engaging case for how to regulate, on the one hand, and demonstrate responsibility, on the other, in emerging technologies. Paper IV explores these issues through analyzing a scientific debate on regulating carbon nanotubes. At the end of 2019, ChemSec announced the placing of carbon nanotubes onto the SIN List (Hansen and Lennquist 2020.) The SIN List is moreover designed to evaluate chemical substances with the exact criteria of the European chemicals legislation REACH in the Substances of Very High Concern (SVHC) candidate list.

Two camps are identified in the results of an argument mapping surrounding the issue of substituting carbon nanotubes. The yes/substitute camp contains three arguments: the hazard argument (carbon nanotubes are hazardous according to REACH), the asbestos argument (carbon nanotubes are comparable to asbestos), and the regulatory feasibility argument (regulating carbon nanotubes as one grouped nanomaterial is most feasible). The no/business-as-usual camp consists of six arguments. One, the case-by-case argument says that carbon nanotubes are too diverse to be regulated in the aggregate. Two, the science-based regulation argument is that regulation should be predicated on (and only on) scientific knowledge. Three, the precautionary argument asserts that the carbon nanotubes industry follows a precautionary mindset and does not require further regulation. Four, the lack of standardization argument finds that differing standardizations of the safety research make the resulting studies inconclusive. Five, the safe-by-design argument counters that carbon nanotubes should instead be made safe by modifying their hazard profile and exposure conditions. Six, the progress argument warns that carbon nanotubes, as a symbol of necessary progress, will struggle to become safer, as a product of the endangered investment from SIN List stigma.

Three separate end values are shown to motivate the debate, (1) environmental protection and human safety, (2) good science and (3) technological progress. Both camps propose their positions as guarantors of safety with carbon nanotubes as ambivalent vectors of risk and simultaneously targets of alternative risks. Good science is promoted by the no camp as the necessary criteria to inform regulatory decision-making. Technological progress—here in the belief that carbon nanotubes, can, should and will be made safe–divides the camp across the schism between notions of progress and precaution.

There are four scientific contributions from Paper IV. First, this debate can be situated as a controversy study, not only regarding knowledge production, but into adjacent regulatory decision-making. Second, Paper IV displays how actual scientists, outside the scope of RRI, can attempt to take responsibility in a reflexive and anticipatory capacity beyond the normal practice of nanotoxicology. This contributes to RRI scholarship to see how scientists understand responsibility. Third, Paper IV generates an argument mapping that can be refined through future applied ethics research. Fourth, the argument in Paper IV signals an explanatory role of "implicit values" in this technical-normative debate. An implication is that regulatory contestation amongst scientists can be resolved with attention to *normative*, as opposed to a mere *technical* focus. This contributes to discussions of value-ladenness in STS and applied ethics.

Paper V

Paper V shifts the empirical focus from carbon nanotubes to the underlying SIN List. Rather than the Paper IV study of scientists' deliberations on whether a particular nanomaterial should be placed on the list, Paper V explores how professionals in the industry are using the list, in addition to broader stakeholder perceptions. Specifically, the article interrogates how stakeholders perceive and assess the credibility of the claims about future regulation made by ChemSec. Moreover, it explores how professionals—as well as ChemSec itself—reflects on how the SIN List alternately describes the future, but in doing so also shapes the future.

The analysis is wedded to the influential work of sociologist Jens Beckert (2021; 2016; 2024) on fictional expectations in economic life. Thus, it engages with Beckert's work on three levels. First, Paper V responds to Beckert's general program of providing a sociological micro-foundation to political economy by stipulating that "fictional expectations" serves as a foundation of economic action (see Fourcade et al. 2023.) Second, it studies fictional expectations in individual organizations, exploring practical uses of an "instrument of imagination" (the SIN List), published by a "promissory organization" (ChemSec.) Third, it looks at the specific question of what makes fictions about the future credible.

Through interviews, Paper V presents a picture of how stakeholders engage with fictive expectations, specifically characterized in the concept of the "regulatory fiction", that is broadly in line with Beckert's original presentation. They are shown to follow a particular rationality that stems from an acceptance of the fundamental indeterminacy of the future. Indeed, some of them express a reflexive understanding of how the

supposed prediction of futures also amount to a political shaping of futures. Further, the article emphasizes the scientific components of how fictions are made credible, and conversely downplays the dramaturgical mode of explanation provided by Beckert (2024.)

Paper V offers four scientific contributions. One, it gathers various perceptions of the SIN List that relate to the general use of soft regulation, specific to chemical safety and management, in advance of regulatory movement. Two, the SIN List provides a case study of a regulatory fiction as an additional type of fictional expectation, as initiated by Beckert (2021.) Three, as such, the findings validate Beckert's above general program connecting political economy to economic sociology. Four, Paper V concretizes the normative elements from the technical-normative debate in Paper IV, in terms of supplemental social and economic motivations, as opposed to factors perceived as technical. This suggests that economic sociology is relevant to future studies of soft regulation.

SEVEN/ **ANALYSIS**

This section analyses the appended papers with the aid of the **theoretical framework**, as established earlier. Key terminology orienting this framework of sub-politics has been listed on **Table 1** on page 20. The analysis is structured in terms of the three research questions, emerging from the **theoretical framework**, that have been introduced in **Table 3**, on page 25. As such, the section identifies and analyzes the multiple sub-polities, sub-policies, and sub-politics explored in this thesis, through the appended papers. These subsequent responses and their parent research questions are summarized by **Table 7** below.

RQ1: Sub-polities

All five papers can be understood through sub-politicization (defined earlier as "emergence of opportunities" for sub-politics) and the constitution of various sub-polities (the earlier "organizational settings".) Paper I refers to abstract sub-politicizations of progress, in lieu of any empirical sub-polities, in presiding technoscientific capitalism. Paper II concretely details a sub-polity of scientists galvanized by RRI through its formulation of "the bubble." Stakeholders publishing and patenting in four domains of nanotechnology development, from Paper III, constitute additional sub-polities. Paper IV oversees another sub-polity of scientists that debate on carbon nanotube regulation. In Paper V, there is another sub-polity of stakeholders, centered around an interest in anticipating future chemicals regulation, especially for professionals using the SIN List.

Paper I assesses the current state of technoscientific capitalism, which can be analyzed in the potential for sub-politicization around progress. At an aggregate level, this refers to developments within both the institutional spheres of politics and non-politics. Nanotechnology, as a locus of research and innovation activity, necessitates financial support from the political system. This support can be legitimated in part through the Beckian "harmonizing formula", equating the modern end values of social progress to the means of technical progress. However, as demonstrated in the **introduction**, nanotechnology has been shaped by the promised commercial utility of research and innovation. Technical, and techno-economic, progress is the intended endpoint of nanotechnology, which is not necessarily convergent with society and social progress. This potential divergence can be conceptualized as the *sub-politicization of progress*.

Table 7. Summary of research questions and responses

	Research Question 1	**Research Question 2**	**Research Question 3**
	How are the *sub-polities* of nanosafety and innovation organized and instituted?	How are *sub-policies* articulated through *sub-polities?*	How are *sub-politics* expressed by *sub-polities* and *sub-policies* of nanosafety and innovation?
Paper I	Sub-polities in technoscientific capitalism can develop from institutions of non-politics (e.g. nanotechnology research and innovation organizations) and politics (e.g. policy organizations) in the *sub-politicization of progress*	–	–
Paper II	*Sub-polities of RRI* consist of critical and reflexive scientists aiming to address an insular "bubble" formation within science	Explicitly produces a *sub-policy of commitments* from RRI scientists, in an attempt at reflective self-regulation	Reflective commitments as self-regulation comprise an agora forum in a scientific journal, without direct conflict, but with *sub-politicking of RRI scientists*
Paper III	Identifies stakeholders engaged in multiple *sub-polities of nanotechnology development*, especially organized around centers of nanotechnology *contra* environmental nanosafety	Nanotechnology development offers segregated *primary versus reflexive sub-policies*, in terms of nanotechnology domains separated from environmental nanosafety research	Dual *sub-politics in the nano-race* framing occurs in winning through nanotechnology knowledge production (primary), however segregated and reflexive environmental nanosafety research suggests organized ambivalence

Paper IV	Presents a *sub-polity of carbon nanotube regulation* in scientific debate, connected to nanotechnology development	Instead of a monolithic regulation of carbon nanotubes (Beckian 'policy'), the *SIN List as an instance of sub-policy* still produces regulatory as in political effect, shown by the debate	*Sub-politics of ambivalence* is further demonstrated in the scientific journal forum by elements of structure, namely the hybrid "arena-as-agora" against either arena or agora, and output in the lack of clear resolution
Paper V	Stakeholders engaged in *sub-polities to anticipate chemicals regulation*, specifically substitution in the SIN List, allows for an institutional constellation including both techno-economic organizations and civil society (NGOs)	Elaborates on the anticipatory function of *sub-policies like SIN List* that facilitate its movement from political origins in advocacy to be neutralized into rote Beckian 'non-policy' routines	Governance through regulatory fictions reveals the emergence of a new organizational form in civil society that engenders voluntary *soft-* and *self-* regulatory practices on a logic and *sub-politics of subscription*

Note: SIN List is an abbreviation for the Substitute-It-Now List, published and maintained by ChemSec.

Society, to be plain, is being given techno-economic innovation in the form of economic commodities—nano-enabled products are veritable tokens of progress. Scientific, technological and economic institutions, alongside the political system, are therefore all relevant institutions which contextualize representation in sub-polities to the extent of divergent, or per Beck, disharmonious progress. Considering the demand for legitimacy and the economic rationality of nanotechnology, the recent emphasis around responsibility is a topical case in point, with its implied moral authority.

This pursuit of responsibility travels from these generalized institutions into more tangible sub-polities of RRI. Paper II documents and critiques the *RRI sub-polity known as "the bubble"*, inhabited by insider RRI scientists, while separately composed by a group of ECR scholars that are also members of this community. As compared to Paper I, this is predominantly a space of scientists working to realize RRI amidst both a historical moment and discourse of responsibility. While "the bubble" is organized around policy-derived normative concerns for research and innovation, the wider institutions of technoscientific capitalism remain in the background. Steering of research and innovation is foregrounded—tacitly tied to the logic of emerging technologies—rather than nanotechnology.

Nanotechnology development is however the empirical topic of Paper III. This paper examines multiple levels of *stakeholder sub-polities across nanotechnology*, moving from general nanotechnology to the two specific nanomaterials and ultimately the environmental nanosafety research field. Instead of a research community, Paper III stresses sub-polities of stakeholders in nanotechnology development regarding each of the four domains. These domains are demonstrated to be aligned to either nanotechnology or environmental nanosafety, as the constitution of environmental nanosafety stakeholders is comparatively disparate. Hence nanotechnology development can be seen in two separate organizational forms: sub-polities of nanotechnology and also environmental nanosafety.

Paper IV returns to a focus on scientists and discourse, which resonates with Paper II. This is a *sub-polity of carbon nanotube regulation*. While Paper II develops as a self-critique of RRI scholars, Paper IV evinces the value-laden nature of a regulatory debate regarding carbon nanotubes, one of the four domains in Paper III. This debate, congruent with the predictions of sub-politics, is situated outside of regulatory authorities and the political system, but inside of scientific journals. The contributors here are also not actual regulators, but again scientists with approximate associations to the above domain of environmental nanosafety and the research field of nanomedicine. They could consequently belong to the sub-polities invocated by Paper III, in addition

to their contributions regarding the sub-polity of carbon nanotube regulation. These engaged scientists can also be considered as agents in the institution of science responding to sub-politicizations of progress in technoscientific capitalism, as framed by Paper I.

Besides the institutional arrangement that motivates Paper I, the above Papers II, III and IV seek to problematize practices within diverse sub-polities of research and innovation. This is demonstrated through the empirical attention to scientists and their work. Paper III uncovers multiple constellations of stakeholders significant for their production of research and innovation in nanotechnology, be it either academic papers or commercial patents, and distilled into academic institutional affiliates, research funding groups and patenting organizations. A small sample of these types of scientists—to wit, nanotechnologists–can be understood to engage in the normative debate on carbon nanotubes from Paper IV. Here it is not the quantity of their contributions to nanotechnology development organizing the sub-polity, but rather the *normative quality* of discursive argumentation and justification. Paper II therefore amounts to an orthogonal meta-perspective of reflexive scientists seeking to influence and alter practices of research and innovation.

Paper V moves the analysis to anticipating chemicals regulation, especially its relation to substitution in the context of the SIN List. This is another manifestation of *sub-polities for stakeholders engaging with this anticipation*. It departs from the observations around regulation in Paper IV, responsible development of nanotechnology in Paper III and community of RRI scientists in Paper II to discuss activities outside the institution of science, pertaining to techno-economic institutions of business and civil society. Instead of separating these latter institutions, Paper V uses the concept of regulatory fictions to engage with the organizational rationalities in acting around the anticipatory management of chemicals and materials, in lieu and in advance of regulatory developments. These organizations are stylized as both traditional for-profit companies and novel technical consultancies—hence emblematic of *technical* and *economic* institutions. What is more, the combined contours of expertise, uncertainty, decision-making and normative advocacy yield interstitial space for environmental NGOs, occupied for example by ChemSec. Beyond just professional SIN List users, this is another area for sub-polities of anticipatory stakeholders.

RQ2: Sub-policies

Sub-policies (defined earlier in the emergent outputs of sub-politics in sub-polities) are identified and elaborated upon in Papers III, IV, V, and finally, Paper II. Paper III

articulates an evidenced segregation between primary and reflexive sub-policies of nanotechnology development. Both Papers IV and V relate to the specific sub-policy of the SIN List. The carbon nanotubes debate in Paper IV illustrates its capacity to fill a regulatory void, allowing decision-making. Paper V then is used to explain its anticipatory and descriptive functions. Another instance of sub-policy comes from the self-regulating commitments of Paper II.

Research and innovation, as inventoried through papers and patents, is central to Paper III that indicates *primary versus reflexive sub-policies of nanotechnology development.* The organizational separation between nanotechnology development and environmental nanosafety implies dual sub-polities as a basis for action from the produced knowledge. This is a basis, in other words, for subsequent decision-making derived from sub-policies, while recursively dependent upon other sub-policies that condition the research and innovation practices. Considering the observed empirical segregation, this could extend to the production of sub-policies. By extension of Beck's diagnosis of primary and reflexive scientization in the **research context**, the first three domains of innovation activity could be posited as sub-polities suitable to primary sub-policies, in contrast to environmental nanosafety activity with reflexive sub-policies.

The debate on carbon nanotubes from Paper IV underlines the limits of regulation and the potential of the *SIN List, as sub-policy*, to fill the policy void. Decisions in this sub-polity are being made explicitly due to classification of hazards, formalized under regulatory procedure.[43] This *status quo* procedure can be reframed as 'policy' in the vocabulary of Beck. Paper IV nonetheless removes the presumed objectivity and monolithic, technical qualities in the production of policy, by exposing the "implicit values" mobilized through the debate. Norms and ideals of science and regulation are rendered visible as relevant negotiating criteria in the attempts to settle the debate and ultimately determine a credible 'policy' (regulation.) This makes plain the relevance of not only expert production of knowledge, but moreover expert frames of interpretation. There is no singular objective nor moral policy to regulate carbon nanotubes, despite any contingent juridical processes.

Paper V emanates from the same context of Paper IV, in the addition of carbon nanotubes onto the *SIN List, again analyzed as sub-policy*. Yet, Paper V turns from the regulatory debate inspired by this listing to the constitutive organization: ChemSec. The

[43] By regulatory procedure, the implication from Paper IV is delimited to the EU regulation of chemical substances, which has been amended for nanomaterials (see Nielsen et al. 2023.) At its core, this consists significantly of CLP (European Commission 2008b) and REACH legislation (European Commission 2006.)

SIN List is argued to be another impetus to decision-making, alongside regulation, with the key difference being the motivations of voluntary responsibility versus (legally) involuntary compliance. In using the SIN List, decisions can be made from the perspective of sub-policy, i.e. regardless of ultimate inclusion of a substance according to specific legislation. One advantage of a sub-policy like the SIN List beyond coordinating information and eliminating uncertainty that expertise provides is this ability to act in anticipation, with the expectation of uncertain yet constant future regulation. Sub-policies, as exhibited by Paper V, can demonstrate and perform these *temporal* dynamics of expectation when the horizon is equated to a regulatory fiction. Simultaneously, sub-policies are performed by the present and presumed future *social* environment.

Temporal dynamics aside, the SIN List also speaks to the corollary sub-policy of Beckian 'non-policy' that could facilitate its instrumental uptake by professionals. Using the SIN List can yield economic benefits, but it is furthermore embedded with a political agenda, i.e. goals and programs, from civil society in the form of an environmental NGO: ChemSec. This can be related to other programs to alter chemicals and materials planning, as discussed in Paper V, for instance with sustainable chemistry or general chemicals management.[44] As sub-policy, the SIN List is generally recalled as an advocacy tool by the respondents in Paper V. Nevertheless, it can be used as an expert source of information in other, more downstream, decision-making matrices. The SIN List is remarkable for its capacity to be assimilated into rote, Beckian 'non-policy', as in unquestioned routines, within the sphere of non-politics.

The SIN List is therefore imbued with features of both institutional spheres: politics (Paper IV) and non-politics (Paper V.) It can be bundled together with, and within, other toolkits. There is no explicit demand for professionals outside this sub-polity to advocate, for instance, in adopting a chemicals management strategy, action plan, or to 'join the movement'.[45] The SIN List can be used tacitly to advocate, or, just as a good tool. Hence, its success can be partly explained by taking political aims and objectives of civil society (exemplified here by ChemSec) into routine procedure by industry and business. These professionals can have little or no affiliation to the sub-polity that actively anticipates chemicals regulation, but can regardless attempt to make a difference through their techno-economic behavior and into actual material flows.

[44] Some of the interviewees refer to a need for, or their own, 'chemical action plans' that can embed principles from sustainable chemistry, amongst other platforms.
[45] The phrase is reiterated on the ChemSec website. For instance, see: https://chemsec.org/the-pfas-story-how-did-we-end-up-here-and-what-can-be-done-about-it/

Rather than transcend these institutional boundaries, Paper II performs an ostensive act of self-regulation amongst scientists involved with RRI. This is understood here as a *sub-policy of commitments*. The paper discursively speaks to a sub-polity of RRI, from within "the bubble", to propose a series of commitments, addressing the multiple problems framed as discomforts. This is sub-policy through self-regulation. It has little chance of assimilation into Beckian 'non-policy' routines due to its reflective and not automatic or axiomatic character. As a program, these commitments are loosely formed and inimical to compliance.

RQ3: Sub-politics

Sub-politics, presented earlier as "generalized political action" outside the institutional sphere of politics, including sub-politicking (defined earlier in the self-aware "performance aspect" of sub-politics), are analyzed in Papers II, III, IV and V. The scientific journal forum is introduced as an agora in the sub-politicking of RRI scientists by Paper II. Paper III represents an arena model of sub-politics through conflicts of the nano-race, yet also ambivalence in the documented segregation between nanotechnology development as innovation and environmental nanosafety. Paper IV furthers this sub-politics of ambivalence, turning to features of structure and output in a situation already noted in the paper as "arena-as-agora." Regulatory fictions in the SIN List elucidate a logic and sub-politics of subscription in governance, over compliance, that allows for novel organization.

Paper II illustrates the deliberative agora model of sub-politics in the *sub-politicking of RRI scientists*. Paper II is presented in a scientific journal, the *Journal of Responsible Innovation,* as scientists doing science—and not formal politics. These sub-policies of commitments have little potential for conflict, not because of the journal format or the scientific profession, but because of their expression through self-regulation. Political conflict is not the goal. Instead of conflict, there is discursive contestation as deliberation, with the goal to perform reflexive sub-politics in encouraging other scientists to themselves reflect. Simply put, Paper II manifests as sub-politicking, in addition to an exercise of science. This is a sub-political forum which can be referred to as an agora.

The *sub-politics of the nano-race* in Paper III continues from sub-policies a double sub-politics—primary and reflexive—whose segregation implies ambivalence. Races are structured competitively by winners, followed by losers; in other words, this is conflict in the arena model. Organizations that generate or support the most nanotechnology, delimited to papers and patents, are defined as winning the race. This production of

knowledge, in winning the race, engenders (primary) sub-political effects. Yet this sub-politics of the nano-race hides a secondary (reflexive) conflict between the development of innovation and environmental nanosafety. Reflexivity elides the conflict in that, while both races involve scientization, the reflexive scientization endemic to environmental nanosafety infers again the recursive relationship from the **research context**. Environmental nanosafety propagates solutions to problems established as side-effects of innovation. Paper III documents how these separate domains advance over time and how their organization can prevent sub-political conflict. It suggests that primary and reflexive scientization can proceed apace and without significant confrontation, as segregation. Despite the arena model in dueling nano-races of innovation and environmental nanosafety, the revealed segregation of Paper III signifies a sub-politics of ambivalence.

The Paper IV debate on carbon nanotubes further reveals this *sub-politics of ambivalence*, not through segregation, but in the structure and output of sub-politics. Regarding the structure, the debate ensues in another scientific journal, in a similar forum to Paper II, with the above assumptions of contestation and deliberation in the agora model. Here, scientists as experts and as sub-political agents confront each other—explicitly and not reflexively—through salvos of rhetoric mixed with references to scientific literature. This is a debate explicated as a conflict between two rival "camps" on the (specific) question of substituting carbon nanotubes. One will prevail and one will lose, just as indicated by Paper III, which is far from the agora in Paper II. The debate is articulated as an arena, while performed by the contributing scientists as an agora; this point is already remarked upon in the "arena-as-agora" conceptualization concluding Paper IV. This is structural ambivalence. Regarding output, unlike the emphasis of Paper III on quantifiable outputs of research and innovation in nanotechnology, the debate on carbon nanotubes has no resolution. There are no winners or losers yet as the regulatory status is unchanged. The sub-politics, envisaged here as another race, can continue, presumably with new findings. Meanwhile, the SIN List sub-policy listing of carbon nanotubes remains.

Paper V builds on these findings to express the potential for a *sub-politics of subscription* in governance through regulatory fictions. This is the very fiction which triggers the debate on carbon nanotubes from Paper IV. The sub-politics broached by the SIN List and its updates are alternately similar and dissimilar to the politics permeating formal regulatory processes.

On similarity, it allows professionals to make *self*-regulating decisions. They can act as if, for instance, carbon nanotubes are added to the regulation and therefore stop its

production, or minimize its purchase, or reserve it for essential use applications. Moreover, these professionals can act as sub-policy entrepreneurs: to pursue *soft* regulation by messaging and encouraging others along the supply chain to follow suit in the substitution of carbon nanotubes. In this way, against Paper IV, there can be winners and losers in advance of any regulatory development in this onslaught of (anticipatory) governance. Sub-political governance can have regulatory effects. These dynamics, again, are not only social but temporal, and the performative sub-politicking can guide the regulatory process itself. The sub-political inertia generated by this self-regulation and soft regulation helps determine the regulatory horizon.

On dissimilarity, the SIN List lacks the democratic and hence delegated legitimacy of regulation. Professionals can *elect* to subscribe, instead of legally complying to democratic legislation. Regulatory fictions simply offer another reason to subscribe. While the ultimate environmental effects might be comparable between policy and sub-policy, this sub-politics of subscription is distinct from politics. Expertise is pluralized in the movement of spheres from the non-politics of science and technology and the politics of regulation to a pluralistic sub-politics formed here in the crucible of civil society. Civil society, in the setting of Paper V, can remain an arbiter of morality, but this emergent role indicates it is also invested in pluralizing expertise.

EIGHT/ **DISCUSSION**

This section discusses the appended papers in the context of **previous research** on nanotechnology governance. It is structured around the **theoretical framework,** in terms of the three framework pillars explained earlier. The **discussion** traces these three pillars—to reiterate, sub-polities, sub-policies, and sub-politics— from the primary analysis onto the manifold genres recounted in **previous research** on a secondary level. This reveals a series of 14 discussion motifs, introduced and described below in **Table 8,** that each seek to extend earlier conversation points**.** Amongst these motifs, three signal scientific contributions are emphasized, which are predicated upon each of the three pillars (see **Table 9** for description at the end of discussion.) These signal contributions are outlined in terms of the organizational form of promissory advocate, the conceptualization of multiplication of uncertainty, and the tendency towards promissory legitimation crisis.

Table 8. Thesis discussion motifs

Pillar	Motif	Description
Sub-polities	Promissory advocacy*	–
	Risk over responsibility	Risk seen as central problematic instead of broader notions of responsibility (i.e. RRI)
	Ambivalent precaution	The precautionary principle is used in contradicting ways, suggesting sustained ambivalence
	Value versus culture conflict	Conflict amongst nanoscientists manifests at deeper level of values, rather than just culture
	Ambivalent responsibility	Contradictions and ambiguities of responsibility in downstream 'role juggling' through promoting safety and responsibility or innovation
Sub-policies	Meta-regulatory code of conduct	Codes of conduct can be enlisted to meta-regulate soft regulatory action, rather than only to self-regulate research and innovation
	Multiplication of uncertainty*	–
	SbD as rank reordering	SbD allows for a rank reordering of values, with progress preferred over safety when in conflict

Sub-politics	Promissory legitimation crisis*	–
	Unstable division of moral labor	Environmental NGOs disrupt the established division of labor, as they exceed moral critiques to engage with technoscientific progress
	Limitations of agora	While politically idealized, the agora model might not result in decisive soft regulation, which could lead to arena
	Expertization versus scientization	Debates and controversies require resolution through decisive regulatory expertization, regardless of the tendency for indeterminate scientific assessment
	Credible over speculative futures	Future-oriented decision-making assesses the future from the criteria of credibility rather than speculation and hype
	Reflective governance of affect	Affect is an object of governance, mobilized through reflection of scientists, instead of lay publics

Note: the asterisk notation (*) highlights the three signal contributions. These signal contributions refer to **Table 9** at the end of this discussion.

Tracing sub-polities

Based on previous research, three genres of sub-polities in nanotechnology governance can be traced with the appended papers. These will be explored below, from third-party organizations (1), stakeholder and expert perceptions (2) and lastly studying (nano)scientists and reflexivity (3) that collectively intersect findings of Papers II, III, IV, and V. The signal contribution (and discussion motif) derives from Paper V, in gathering stakeholder views surrounding ChemSec through Study C, to introduce the promissory advocate as a novel organizational form.

Intermediary organizations in nanotechnology have been portrayed in at least three ideal types of third-parties—innovation intermediary (navigating complexity), promissory organization (producing expectations) and environmental NGO (offering moral authority and legitimacy.) Paper V indicates an emergence of a hybrid form: the promissory advocate. ChemSec, through the sub-policy tool of the SIN List, evinces the *promissory advocate* as a triadic organization, as *both* innovation intermediary *and* promissory organization *and* environmental NGO. It furthermore pursues three kinds of authority: scientific, regulatory, and moral.

As an intermediary, ChemSec is seen to exude scientific authority. It can operate transnationally (not dissimilar to OECD, see (Falkner and Jaspers 2012)) and is shown to be capable of accumulating and communicating scientific information to mitigate complexity via the SIN List and its other tools (cf. Mount, Milewski, and Fernandes 2015.) ChemSec also engages directly with the scientific community through journal articles, for instance the controversy analyzed in Paper IV (Hansen and Lennquist 2020) and elsewhere (Lennquist et al. 2024.) Still, ChemSec operates without the official status or perceived neutrality of the previous EU nanotechnology monitoring organization 'ObservatoryNANO' (see Åm 2013.) [46]

As a promissory organization, ChemSec tries to mimic regulatory authority. It maintains the SIN List that performs the regulatory fictions, as a kind of expectation, expanded upon in Paper V. Based on the earlier focus with the nanotechnology-centered Lux Capital in (Ebeling 2008), ChemSec expectations appear to be more transparent, aiming instead at reflexive professionals like chemicals managers less interested in hype. Due to their posture facing regulatory horizons with regulatory fictions, ChemSec is revealed to pursue complementary regulatory authority, while not in fact being a public regulatory agency.

As an environmental NGO, ChemSec additionally works with fostering moral authority. The organization can be characterized generally as pursuing "invited participation" (Wehling 2012), either with stakeholder or government-sponsored collaborations, for instance regarding the ChemSec Business Group, Marketplace tool, webinar series, or in the EC Joint Research Center reports on SSbD (see Study C under **methods.)** [47] However, there seem to be additional practices that qualify as "uninvited participation", namely, with online commentary on regulatory developments, video

[46] ChemSec is also not entirely a government-independent NGO from a funding perspective. This background was raised occasionally by interviewees in Study C. In their 2023 Financial Statement (ChemSec 2023, 3,8), they describe the arrangement as: "total income in 2023 was SEK 16,304,956 kronor (16,018,293.) The largest contributor was the Swedish Government through a general grant", with a general self-definition that "ChemSec is a non-profit organisation without religious or political affiliations that advocates for greater protection from harmful chemicals for the environment and people's health." (The currency SEK refers to Swedish kronor, i.e. crowns.) They list, to be illustrative, funding from the Swedish Chemicals Agency and Swedish foundation for strategic environmental research, Mistra. To be forthcoming, this PhD project is also funded in part through Mistra (see **methods.)**

[47] Again, interviewees from Study C also remember other instances of invited participation. Some of these regard research settings, and others on stakeholder dialog settings for regulation and policy development.

content, and the ChemScore tool.[48] ChemSec, put together, attempts to project dual NGO standpoints. They seek to convince professionals to do the perceived 'right thing' and substitute undesirable SIN List substances (cf. Miller and Scrinis 2010), through its reluctant promotion of soft regulation via the SIN List. Yet simultaneously, they advocate to expand, and not replace, formal regulation (cf. Balbus et al. 2006.) ChemSec tools, like the SIN List, are then not a repeat of the earlier Environmental Defense and DuPont partnership (see again Krabbenborg 2013; 2020.) In this way, ChemSec is understood to pursue and wield moral authority. Finally, the findings of Paper V imply a degree of input legitimacy to governance practices through their triple authoritative status, despite being an NGO (cf. Bowman and Hodge 2010.)

The promissory advocate should thus be seen as a hybrid of existing and previously examined organizational forms in nanotechnology. The activities of ChemSec are perhaps most distinctive in combining an NGO rationality with profit-seeking examples in intermediaries and promissory organizations. Its advocated promises, established with regulatory fictions, are not simply structured as novel attempts encouraging profit motive through degrees of performative action. These promises are not just various nano-enabled futures imbued with techno-economic progress, as would be characteristic to Lux Capital. It also does not seek to entirely restructure technoscientific capitalism as could be expected for an (idealistic) environmental NGO. Rather, it *advocates,* partly through regulatory fictions, for its subordinate values to protect human health and the environment by combining technoscientific and regulatory expertise in situations of endemic uncertainty that nevertheless demand strategic action by professionals. The promissory advocate, in sum, is suggested to be first and foremost an advocacy organization—most often an NGO. This advocacy hence resonates with Hess' previous formulation of the nanotechnology "environmental reform organization" (2010), that nurtures and wields these intermediary and promissory tools.

Stakeholder and expert perceptions are another genre of sub-polities applicable to the appended Papers III, IV, and V. Together they can inform previous research on attending to reflexivity in risk and responsibility, and ambivalence in the precautionary principle. Two discussion motifs are elaborated here: risk over responsibility and ambivalent precaution.

On risk and responsibility, Papers III and V locate a continued reliance on *risk over responsibility*. This motif refers to risk framing and problematization over responsibility,

[48] The ChemScore tool can be browsed from the ChemSec webpage: https://chemscore.chemsec.org/. While not part of Paper V, it is mentioned in Study C.

usually associated with RRI, but limited by the extent of displayed reflexivity. Paper III enlists a narrow risk framing to evaluate progress in the recent nano-race, using a reflexive perspective separating concerning domains (i.e. carbon nanotubes and nano-silver) versus environmental nanosafety research. This is outlined in terms of previous calls to incorporate broader responsible innovation principles—like, to name one study, Malakar and Lacey's (2023) emphasis on inclusion and reflection. One implication from Paper III for broader responsibility is that risk remains a core normative concern in altering research and innovation trajectories. Consequently, reflexive capacity building seems fundamental, whether or not it is operationalized under frameworks of RRI, SSbD, or some future iteration. Paper V, although emphasizing a case of soft regulation, again repeats the evidenced focus on risk over responsibility (Grieger et al. 2021; Shelley-Egan and Davies 2013), finding stronger evidence of reflexivity than Paper III. It is evident as a principle in the interviews (Paper V) with the qualifier that organizational culture for industry stakeholders is a key perceived determinant to exceed the required regulatory compliance (cf. Köhler and Som 2008.) Soft regulation could hence be part of the reflexive capacity building, yet it should be noted that these tools are established features of nanotechnology governance. This could speak more to the "demand for command" (Stokes 2013) than increased, albeit voluntary, reflexivity mediated in sub-polities.

The precautionary principle, while important to Papers III, IV and V, is demonstrated to underscore continued ambivalence in practice. This motif is called *ambivalent precaution,* and is surprising, due to its perceived discursive legitimacy (that is, legitimacy through negotiations in discourse) and potential for instrumentalization. As a hypothesized decision-making approach for Paper III, it is not clearly supported by the results through any observed substitution. In their argumentation, the two camps in Paper IV's debate both rhetorically invoke the precautionary principle: one camp asserts substitution as precaution, opposed to the other stressing carbon nanotube development as already precautionary. Paper IV thus reveals *prima facie* ambivalence but moreover its potential to discursively legitimize a decided plan of action using moral authority. The precautionary principle is comparable to the refrain of responsibility in technoscientific innovation processes, by challenging critics to counter with another moral principle or to discursively reframe it (cf. Saldívar-Tanaka and Hansen 2021.) Sub-polities of nanotechnology governance, to the required degree of discursive legitimacy, are organized around and through contesting these moral principles—a point made transparent in the ambivalence of Paper IV. Paper V, and the wider Study C, center less on the principle's authority and legitimacy but instead its instrumental use as an early warning. Against findings of "stigmatization" (Saldívar-Tanaka and Hansen 2021), the SIN List, as operationalized precaution for early warning, is compatible as an

embedded tool for governance. It could also relate to the three precautionary restrictions supported previously by (Throne-Holst and Stø 2008.)

Nanoscientist views on the above risk and especially responsibility, are also captured through Papers II and IV. They respectively stress attending to values and culture and reinforce findings of ambivalent responsibility that extend from the precautionary principle. This leads to two more discussion motifs: value versus culture conflict and ambivalent responsibility.

Paper IV's culminating three "implicit values" insinuate the potential for conflict between good science, environmental protection and human safety, and technological progress. That potential resonates with van Hove and Wickson's previous study (2017) that reveals clashing cultures of the same "good science", internal to nanoscientists, and an RRI introduced externally by outsiders. The difference lies in Paper IV's emphasis on contrasting values amongst nanoscientists, rather than seeking to impose a new culture, as in RRI, from outside. This motif is termed a *value versus culture conflict.* Paper II instead clearly embraces the "expansive version" (Davies, Glerup, and Horst 2014) of social responsibility in the five commitments that can be read as another instance of "bottom up responsibilities" against top-down RRI (Glerup, Davies, and Horst 2017.) The commitments of Paper II—stemming from culture versus specific value mobilization—are moreover attuned to professional opportunity costs of ECRs likely to require careful prioritization.

In either Paper II or IV, responsibility remains ambivalent, as already demonstrated with the precautionary principle. This leads to a similar motif of *ambivalent responsibility.* Paper IV sketches dueling camps, replete with contrasting responsibilities and differing assignments of risk, while the commitments of Paper II offer little that is ready for reification. The nanoscientists of Paper IV are situated downstream of primary innovation, yet their deployment of reflexivity includes the perceptual risk (see **research context)** to progress typified as innovation that is expected more from innovators themselves (cf. Johansson and Boholm 2017.) The commentaries in Paper IV provide support to the general reflection on downstream role juggling, while a disparate role from that of social scientists in nanotechnology, as recounted by (Schuijer, Broerse, and Kupper 2021.) Paper II similarly enrolls reflexivity with discomforts and commitments, as compared to "dilemmas" and "roles."

Tracing sub-policies

Three of the sub-policy genres of previous nanotechnology governance research are applicable to the appended papers. Earlier genres of codes of conduct (1), information and coordination tools (2) and safety-by-design (3) can be traced by findings from Papers II, IV and V. Papers IV and V, that concern the SIN List, are reconsidered to enunciate the signal contribution of a multiplication of uncertainty. Two additional discussion motifs are explored: a meta-regulatory code of conduct and SbD as rank reordering.

The commitments of Paper II resonate with and share the general limitations of sub-policies established as codes of conduct. Its commitments advance notions of a code of conduct in positioning towards meta-regulatory *researchers on responsibility* and not ostensibly *responsible researchers and innovators* that pervade previous research. This motif is thus denoted a *meta-regulatory code of conduct.* Rather than analyze an existing code of conduct that characterizes the genre, Paper II backgrounds and composes a new code, albeit for researchers on responsibility and not researchers and innovators *per se*. The five commitments in Paper II can be presented as another attempt at "responsibilization" from (Dorbeck-Jung and Shelley-Egan 2013), while pursuing responsibility in a reflexive manner. They are more comparable to Kjølberg and Strand's perceived "awareness of moral choices" by (nano)scientists and not, however, ourselves as ECRs assigned to be meta-regulators. To be candid, there is no meta-regulatory accounting in Paper II, only a tentative attempt at self-regulation. This limitation that regards both legitimacy (commitments not tied to any authority) and efficacy (commitments not aligned to any meta-regulation nor co-regulation), questions their practical utility (cf. Bowman and Hodge 2009.) Rather, these limitations might inspire other scientists engaged with *Journal of Responsible Innovation* to similarly act with reflexivity, as this self-regulation incurs few opportunity costs on a readership explicitly defined by a research agenda encouraging reflexivity. As such, Paper II can be construed as an act of self-regulation, amongst proliferating codes of conduct, in the meta-regulatory context of fostering responsibility in wider research and innovation.

Information and coordination tools are applicable to the sub-policy of the SIN List, as established in the **analysis.** It features across Papers IV and V. Compared to previously studied and mostly descriptive tools, the SIN List is further embedded with *performative* and *reflexive* features. The SIN List is first compared on a tool-to-tool level within this genre of previous research. This comparison proceeds, second, to an evaluation of the larger predicament facing professional users of such tools. The predicament is understood as a paradox termed the multiplication of uncertainty.

To compare, the SIN List is unlike the earlier Nanodatabase (see Hansen, Hansen, and Nielsen 2020) or voluntary nanomaterial registry (see Bowman and Ludlow 2009) in three ways. This highlights the above three features of description, performativity and reflexivity. One, while it now lists carbon nanotubes, as detailed by Paper IV, the SIN List is designed to describe hazards of chemical substances and not nanomaterials. Two, the tools highlighted in previous research to help coordinate nanotechnology development operate in a void without a formal regulatory process or scientific consensus. Yet, the void is not applicable to the SIN List, as is aligned towards the current REACH legislation. Instead of filling a void, the SIN List gathers scientific information on chemical substance hazards, which is then used as an advocacy tool by ChemSec to encourage voluntary substitution and eventual regulation. Primary description (i.e. the ambit of the nanomaterial-specific tools) and secondary performativity both galvanize rationales to use the SIN List, as reported in Paper V's results. This performativity is arguably an indicator of efficacy in soft regulation that alone sparks the debate in Paper IV and partly legitimizes the SIN List as a whole. Against (Bowman and Ludlow 2009), the SIN List is not intended as a replacement to regulation, but as a complementary catalyst. Three, Paper V uses interviews to establish that stakeholders and the surrounding sub-polity reflexively recognize both the descriptive and performative features. Paper V indicates the desired coordination benefits of a tool designed for chemical substance hazard evaluation, which itself has been viewed as a simplistic foil to the presumed inapplicability of chemical risk-based approaches for nanomaterials.

The SIN List clearly is both a descriptive tool, as per previous research, and a sub-policy, as revealed in the earlier **analysis** in milieux of performativity and reflexivity. Yet clearly it is not alone. It is an expression of soft regulation as expertise that alludes more to a predicament of multiplication, instead of absorption, of uncertainty (cf. Holzer and Sørensen 2003.) This is a consequence of softly regulating under a state of endemic uncertainty—emblematic of technoscientific capitalism–in a regulatory "shadow of hierarchy" (cf. Héritier and Lehmkuhl 2008.) The SIN List operates under multiple types of uncertainty alongside a proliferation of such tools, enabled by the general turn to soft regulation, that cannot be absorbed by any one tool. These are, namely, scientific, regulatory, practical, and hierarchical uncertainties. The *multiplication of uncertainty* indicates not the failure of any one tool, like the SIN List, but the paradox of professionals navigating this predicament of proliferation despite needing certainty through the exercise of expertise.

First, on its own, the SIN List absorbs scientific uncertainty. Professionals are not required to wield toxicological expertise in order to be first informed about chemical

substances believed by ChemSec to be of concern and second to decide to substitute. ChemSec exudes therefore a combined scientific (packaging the latest science) and moral authority (of doing the 'right thing' versus the minimal, economical thing) in its expertise. This contrasts against the juridical authority (passing a final verdict requiring compliance) of regulators.

Second, the SIN List also relies on performativity to absorb regulatory uncertainty. ChemSec advocates for the regulation of SIN List entries in the EU, while simultaneously assuring professionals of this future regulatory development. It deploys Paper V's "regulatory fictions" to convince reflexive professionals, who do not need to be expert on regulatory dialogs, to pursue substitution in the present.

Third, substitution betrays a certain practical uncertainty in the lack of molecular control by professionals over subjected chemical substances. Substitution-aware professionals face, to exemplify, complex value chains, questionable safety data sheets, and the resource-intensive nature of laboratory testing, that limit the capacity to practically and genuinely substitute. These are conundrums residing in the state of chemicals management.

Fourth, the SIN List moreover confronts hierarchical uncertainty: without any *de jure* legal jurisdiction, as soft regulation, there are other "shadow" and implicitly competing lists of controlled substances and decision-making matrices for manifold purposes.[49] Within a jurisdiction, different sectors can have different lists. As documented by Study C interviewees, transnational or multinational companies seek to be informed of many legally binding lists across jurisdictions. This connects to consistent demands in nanotechnology governance to transnational harmonization (cf. Falkner and Jaspers 2012.) [50] Globalization makes sub-policies everywhere, out of formal regulations elsewhere.

The SIN List, to be clear, is a product of this predicament in conducting expertise under technoscientific capitalism, and not a critique of the tool's production. Hence, for the chemicals manager and other professionals, this amounts to a proliferation of

[49] The OECD has recently published a review of "third-party approaches" to chemical substitution, summarizing 33 examples (OECD 2023b.) For one example of such a voluntary list and guidance provider, with no implied recommendation to use it relative to SIN List, see SUBSPORTplus: https://www.subsportplus.eu/subsportplus/EN/Home/Home_node

[50] The US state of California maintains a 'list of lists' approach via its Safer Consumer Products Information Management System (CalSAFER.) One can see different authoritative lists (the jargonistic term for legally binding lists of controlled hazardous substances published by governments) from their webpage after selecting via advanced search: https://calsafer.dtsc.ca.gov/cms/search/?type=Chemical

softly regulating sub-policies, each atomically claiming to absorb uncertainty, yet presiding over a multiplication of uncertainty. Another way to understand the multiplication of uncertainty is in Study C interviewees' imagined goalpost of one universal list of 'bad' substances. Interviewees have expressed this desire to have such a universal list containing all hazardous substances. This speaks to an imagined expertise that absorbs all uncertainty, akin to a panacea for illness, but this is an expertise that unfortunately cannot be found in the SIN List. Failing that, interviewees request a conciliatory and antithetical list of 'good' (virtuous) substances that requires minimal control. Such an actionable list of 'use this, not that' is another manifestation of an imagined expert tool to absorb uncertainty.

Returning to Paper IV, SbD (the sub-policy integrating safety concerns into design and innovation) emerges as an eponymous argument to both avoid regulation and close the debate through scientization. This can be viewed as an expression of values held by experts that reflect the tendency in previous research to belabor SbD as a matter of design and axiology. However, in this case, such values are in conflict. SbD is here understood in the motif of rank reordering.

Paper IV depicts SbD as a sub-policy and as soft regulation, with *inter alia* nanotoxicologists upstream engaging and *softly regulating* innovators instead of official regulators (cf. Miettinen 2021; Suraud 2019.) If the experts with the latest knowledge, that is, nanosafety scientists, can collaborate with innovators, then regulatory experts less advanced on the latest technoscientific complexities would then seem anachronistic. Yet, Paper IV demonstrates a de-politicizing settlement on "the rank ordering of values taking place" (Kelty 2009.) Two of the "implicit values" of Paper IV, good science and technological progress, are claimed to merit a higher "rank ordering" above environmental protection and human safety. In the simplest of terms, for the contra substitution camp, carbon nanotubes *made* safe by design inhabit a higher "rank ordering" than the pro substitution camp's carbon nanotubes *left unmade* due to a substitution sub-policy like the SIN List. Restating (Schwarz-Plaschg, Kallhoff, and Eisenberger 2017), what seems like non-political, technoscientific expert decision-making through SbD, is actually sub-politics by other—technoscientific—means. Moving from regulatory and political expertise to the technoscientific sort is not just a matter of relocating sub-polities stacked with the correct experts but also an axiological "rank [re]ordering of values." This situation is therefore captured under the motif of *SbD as rank reordering*. SbD, extending from Paper IV, underwrites a sub-policy not of unbridled safety but of technoscientific and techno-economic progress—one *that could also* yield a safer design.

Tracing sub-politics

The appended papers build on four sub-politics genres from previous research on nanotechnology governance. All five papers are traced onto the genres of nanotechnology, nanomaterials and morality (1), controversies and debates (2), expectations and uncertainty (3) and affect (4.) Papers I and III are reassessed to illustrate the signal contribution here of a promissory legitimation crisis, as suggested in the case of nanotechnology.

The first genre, nanotechnology, nanomaterials, and morality, suggests implications to technoscientific capitalism (Papers I and III) and to forms and fora of sub-politics (Papers II and IV.) This is expanded upon through three discussion motifs: promissory legitimation crisis, an unstable division of moral labor, and the limitations of agora.

Papers I and III point towards the potential for a specifically *promissory legitimation crisis.* This crisis tendency can arise from three factors. The first is an overreliance on broad and vague problem-definitions, as detailed by nanotechnology, but common to emerging technologies. The second is that nanotechnology solutions rely more on their specific promissory credibility, which is more prominent than the actual solutions. The third factor is any substantial loss of said credibility, through growing concerns stemming from processes of reflexive scientization.

In the framing of Paper III, nanotechnology solutions are pre-positioned as a response to discursive problem-definitions. Various stakeholders in European nanotechnology research and innovation compete in a nano-race with nanotechnology solutions. This is nanotechnology in the "competition state" as an "empty signifier" (Wullweber 2008; cf. Jotterand 2006.) Each solution—in other words, innovation—must be defined in relation to a problem. These problem-definitions are not given but result from sub-political struggle as sub-policies, where "nanotechnology entrepreneurs" seek broad and vague problematizations to bolster cases for nanotechnology-as-solution (Lindquist, Mosher-Howe, and Liu 2010.) Lindquist and colleagues focus on the nascent and speculative nature of nanotechnology-as-solution in the, for instance, elements of input and throughput legitimacy found in a funding application. However, the winners of the nano-race as inventoried by Paper III are not exempt from documenting eventual output legitimacy in their provision of solutions. The sub-politics of problem-definition is important insofar as the demand for output legitimacy can be modulated by the negotiated vagueness. In this way, the broader and more vague the problem-definition, the more ways nanotechnology can be posed as solution, which is advantageous to nanotechnology entrepreneurs.

Given this breadth of problem-definitions, the argument of Paper I can be extended in interrogating the very provision of two separate solution types by nanotechnology. These are actual (output-oriented) solutions and promissory solutions. Challenges to the provision of solutions indicate a problem of legitimacy.

Regarding solutions, nanotechnology seems to risk an orthodox legitimation crisis in terms of any deficiencies in its provision of solutions, i.e. commercial applications. This is due to its prodigious allocations of public resources in technoscientific capitalism—a point also made earlier in the **introduction**. As Paper I recounts, this is not the historical collapse of the welfare state, as charted by Habermas, with citizens withdrawing a narrowly defined and relatively self-evident output legitimacy. Nanotechnology can rely on discursive legitimacy, winning sub-political struggles for problem-definitions, only to reframe discourse when its solutions might appear to be lacking (output legitimacy.) Nevertheless, the comparison between welfare and competition states stops here. Welfare deficiencies are relatively amenable to formal politics and output legitimacy, whereas the sub-politics of nanotechnology as vague "empty signifier" (Wullweber 2008) are, in contrast, amenable more to discursive legitimacy. Compared to previous techno-tragedies from the **research context,** nanotechnology, reduced to nanomaterials, displays sub-political malleability in terms of its "uncertain object" ontology (Laurent 2013.) This renders traditional output-oriented contestation or novel, sub-political counter-mobilizations (like GMOs) more difficult to sustain (cf. Seifert and Plows 2014.)

A potential for legitimacy crisis in nanotechnology thus exists, which can be seen as a nexus. This nexus is postulated as a loss of promissory *credibility* regarding its solutions and increasing *concerns* within reflexive scientization. Simply put, the winners of the European nano-race in Paper III, and the states that have dedicated their funding, do not genuinely have to provide these solutions in actual fact. Rather, they must show their continued credibility. This is the terrain of promissory legitimacy (Beckert 2020), full of sub-political contestation in selecting preferred imagined futures (see Beckert 2016) that situates Paper V's case study of the SIN List. The production of credible solutions is paramount to nanotechnology as well, because research and innovation is a promissory enterprise that relies upon hype and investment (see again Rip 2006.) One key obstacle for promissory legitimacy, as suggested from nanotechnology, is reflexive scientization. Here, the findings of Paper III disclose continued support to concerning nanomaterial domains, delimited to carbon nanotubes and nano-silver, that are coupled to nanotechnology promises. This situation of continued support despite concern suggests a potential to reflexively sub-politicize these very promises. Sub-policies become

feasible, in selecting alternative problem-definitions less amenable to nanotechnology solutions. The setting of Paper IV outlines how this possibility is already implicit. If the perceptual risk is not contained, then there is an increasing risk of promissory legitimation crisis.

Sub-politics, as applicable to Papers II and IV, are shown to complicate previous understandings of organizing forms and fora within nanotechnology governance. To be clear, this is another aspect for the genre of nanotechnology, nanomaterials and morality. Environmental NGOs, here with ChemSec, destabilize the previous, perceived "division of moral labor" (Shelley-Egan 2010) in forms of nanotechnology organization. Academic journals, as sub-political fora, evince limitations of agora as sub-polities (Swierstra and Rip 2007) that require conclusive sub-policies to avoid "ethicalization" (Ferrari and Nordmann 2010.) As described here, soft regulation as sub-policy might not offer the necessary command to resolve the underlying sub-politicization.

Regarding Environmental NGOs, from Paper IV, the decision by ChemSec to list carbon nanotubes on the SIN List destabilizes the division of moral labor. Hence, this motif is referred to as an *unstable division of moral labor.* The listing is an example of direct economic consequences to nanotechnology development, which is alluded to in Paper IV's progress argument. The SIN listing then contradicts the distant "broader consequences" imagined for NGOs by Shelley-Egan's (2010) industry interviewees. ChemSec engages directly with technoscientific progress using scientific reasoning, rather than moral argumentation. This implies continued sub-politics in an unstable division of moral labor between perceived ideal and actual practice.

Regarding academic journals, Papers II and IV address them spatially as sub-polities. These are presented as established scientific fora indicative of Swierstra and Rip's (2007) idealized and deliberative (throughput) legitimacy in the agora. Despite the idealization of agora, Paper II and IV collectively propose limitations of efficacy, as termed by the motif *limitations of agora*. Journal fora appear antithetical to the earlier emphasis in Ferrari and Nordmann's (2010) "ill-defined fora", of "ethicalized" committees and panels operating as arena. Despite the unusual transparency of the journal forum when understood as sub-polity, Papers II and IV are arguably limited by the weak decisions being made in terms of sub-policies. Paper II's commitments have little expectation of compliance, and the controversy of Paper IV leaves scientific readers without any commitment to act, let alone a clear decision. These papers, on their own, seem to proffer deliberative legitimacy, which indicates they might not support the previous trend to "ethicalized" sub-polities. Still, without clear sub-policies nor formal policies, the possibility of subsequent ethicalization in alternative sub-

polities to deliberate towards such resolution seems probable. Sub-polities, especially those oriented as an agora, depend upon the effective quality of sub-policies, with legitimacy in the balance.

The genre of controversies and debates in nanotechnology governance is informed by the carbon nanotubes controversy from Paper IV. Sub-politics in this controversy reflects a tendency to scientization over the above ethicalization. Yet this scientization can be further specified as expertization, in the distinction between scientific knowledge production and decision-making. This leads to a motif of expertization versus scientization.

In relation to the previous sunscreen controversy (cf. Berube 2008), ChemSec seemingly has a higher degree of scientific credibility, as reported by the interviewees for Paper V. This helps explain the sub-political contention between science and regulation that leaves ethics and values implicit—a situation described earlier in the latent "monitoring model" approach to nanotechnology governance (Bensaude-Vincent 2021.) As predicted, there is no call from Environmental NGOs, citizens or public engagements to flatly ban or pursue a moratorium (cf. ETC Group 2003) on carbon nanotubes. There are also no "ethicalized" ethics committees (Ferrari and Nordmann 2010) established in response to the controversy.

The controversy turns not on the "broader consequences" (Shelley-Egan 2010) or implications of nanotechnology development, but is instead channeled into what can be considered expertization. Science and regulation become sub-political, as the doing of science through these channels often left undone, that is, "undone science", can be seen as a policy victory (Hess 2010.) Too much science, notwithstanding, can give rise to a thicket of policy-mandated scientization, often critiqued as a "paralysis by analysis", as elaborated earlier in the case of nano-silver (Hansen and Baun 2012.) [51] Paper IV, at the level of argumentation, alludes to a distinction within this sub-politics, one not about an incapacity for regulation due to "undone science", but due inversely to the potential for overdone science and undone regulation. This situation can be seen as a fundamental limitation of expert-dominated or expertized sub-politics, as opposed to scientists and scientization pushing for more risk assessment. Hence the motif is denoted as *expertization versus scientization.* Sub-policies like the SIN List are therefore in a position to fill this regulatory and decision-making void, especially where the science appears overdone.

[51] In this way, Hansen's previous work on nano-silver reflexively informs his role in the carbon nanotubes controversy from Paper IV.

Expectations and uncertainty are another genre of previous research, which has been implied by Papers I and III regarding the above promissory legitimation crisis. These aspects are foregrounded especially by Paper V in the employment of *credible* over *speculative* futures typical to nanotechnology.[52] Speculative futures refer to the conceptualization of the future proposed by Selin (2007) as a "legitimating discourse", one that requires speculative visions that generate hype and interest at the outset of an emerging technology trajectory. Nanotechnology, as discussed previously, moves from speculation to credibility in the future-oriented Drexler–Smalley debate (see again Kaplan and Radin 2011.) It suggests that these futures need structure and expectations over uncertainty and fantastical speculation as the emergence matures in the struggle for credibility. This motif is accordingly termed *credible over speculative futures.*

In Paper V, the regulatory fiction underpinning the SIN List is demonstrated to also need credibility to find an audience of chemical managers and other professionals. The SIN List uses credible futures over speculative futures, with a distinct sub-politics of uncertainty compared to the emergence of nanotechnology. Both types of future, in Grove's dissection (2009) of uncertainty, function with the mode of indeterminacy: the future cannot be known because it is the future. In this way, the future solutions of nanotechnology are as unknown as the future regulatory listing of a certain nanomaterial. Yet, in the case of credible futures, Paper V evinces that Grove's (2009) modes of "trust" and "decision horizons" are perhaps more relevant. Professionals in the market for regulatory fictions—built on decision horizons—need to trust their supplier (i.e. ChemSec.) As a sort of expectation, regulatory fictions that support sub-policies like the SIN List thus need to promote credible futures in attempting to mitigate this uncertainty.

On the final genre of affect, Paper II discloses a reflective governance of affect, amenable for sub-politics through the specific ambivalence of scientists. Paper II explicitly uses affect to motivate the reflection with the notion of "discomfort" drawn from (Chadwick 2021.) Discomfort is moreover comparable to the problematization of "public ambivalence" that Kearnes and Wynne (2007) ascribe to UK public perception in nanotechnology. The differences in Paper II are (1) centering the reflection around ECRs as scientists and (2) the implication to use affect in governing reflectively and not purely in anticipation. This defines the motif of a *reflective governance of affect.*

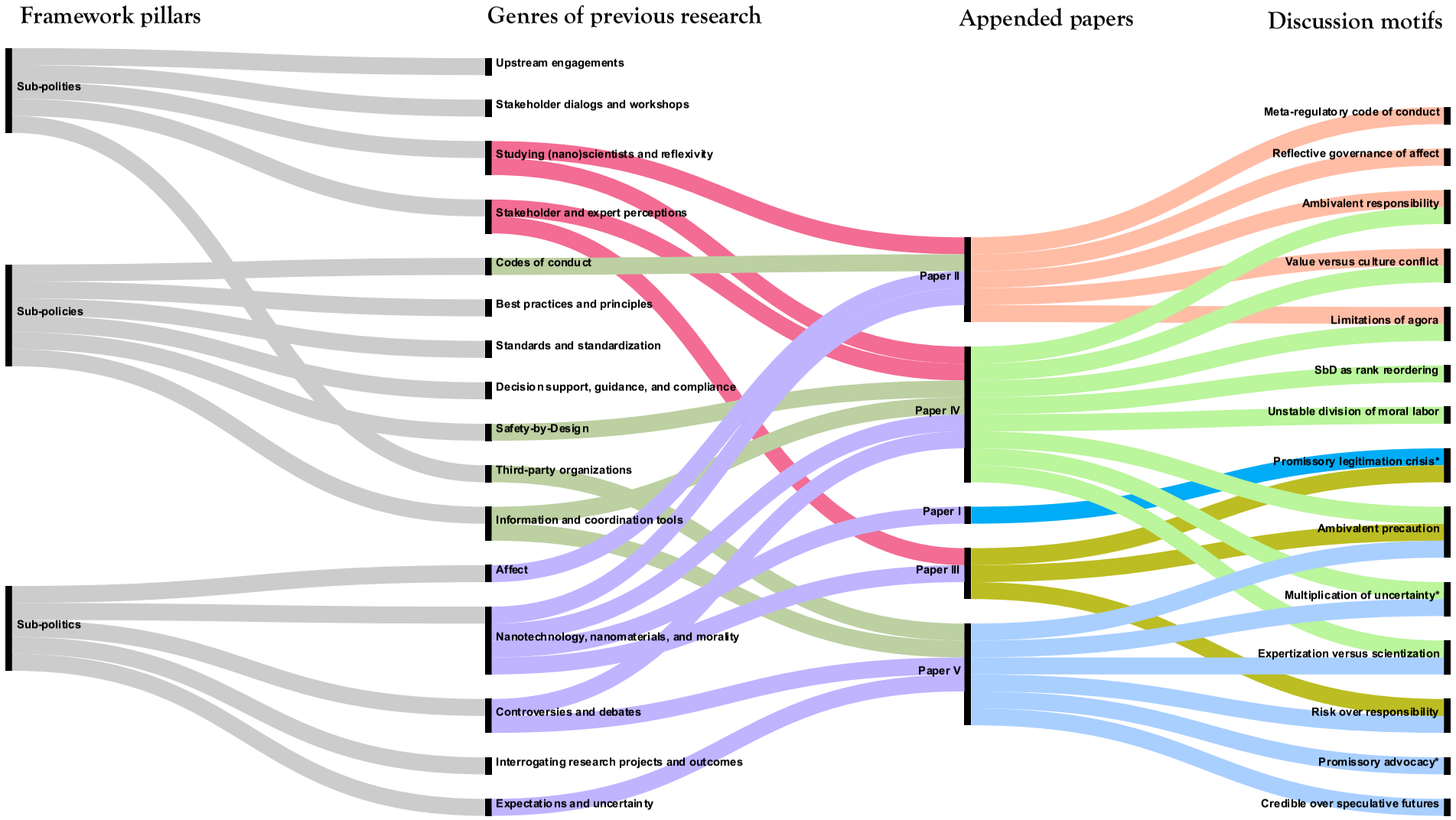
[52] These futures are further specifications of the "imagined futures" in Beckert's monograph (2016) as presented by Paper V.

The commitments of Paper II are imbued with hope and optimism. Moreover, they are definitively future-oriented, like an anticipatory governance approach (see Barben et al. 2008), while also aware of governance through affect (Anderson 2007.) However, they are premised on collective past experiences of discomfort. This invocation of hope and optimism is not intended as a "rational enthusiasm" on the public to resolve ambivalence, but as a proposal to scientists specifically to use, rather than avoid, discomfort. Ambivalence on the part of scientists, as indicated through Paper II, is a "creative resource" (Kearnes and Wynne 2007) for sub-politicization, especially given pervasive soft regulation in the governance of nanotechnology.

Table 9. Thesis signal contributions

Framework pillar	Signal contribution	Field of research
Sub-polities	Introduces the *promissory advocate* organization form, exhibited by ChemSec, that helps to understand intermediary action through third-parties in organizing under technoscientific capitalism	Technoscientific capitalism is developed further as a central empirical concern for PERI
Sub-policies	Proposes that proliferating soft regulation induces a *multiplication of uncertainty,* for professionals, alongside earlier notions of expertise as an absorption of uncertainty, as demonstrated by the SIN List	Governance of emerging technologies offers insights to advance expertise studies (especially studies of sub-politics)
Sub-politics	Nanotechnology reveals the crisis tendency for a *promissory legitimation crisis* at the nexus of a loss of promissory credibility and growing concerns from reflexive scientization, that elucidates dynamics of technoscientific capitalism	Risk sociology through reflexivity posited as generative for the proposed intersection of political economy and economic sociology

Figure 5. Discussion motifs on nanotechnology governance



From left to right, the figure connects the three framework pillars to genres of previous research, the appended papers and culminating series of discussion motifs. Each line, or connection, represents the thesis progression qualitatively and without weighting. The three signal contributions are marked with an asterisk

NINE/ **CONCLUSION**

The thesis presents a visual structure assisted by **Figure 5**, on the previous page. The three **theoretical framework** pillars of sub-polities, sub-policies, and sub-politics trace onto the genres of **previous research** on nanotechnology governance. These genres then trace onto the five papers, which began with the **summary of appended papers** and **analysis**. The previous research ultimately engages with the papers in the preceding **discussion** that traces a series of discussion motifs, including the three signal contributions. This section **concludes** the thesis first by recounting the thesis topic. Second, it revisits the appended papers in the context of theoretical approaches to sub-politics, inclusive of and extending onwards from Beck. Third, it reevaluates the three signal contributions into three separate points of departure.

Nanosafety and innovation

Nanosafety and innovation, in this thesis, have been understood through tensions at the level of sub-politics rather than politics (see **Figure 3** on page 24.) These tensions emerge in between *regulating for* (nano)safety and *regulating to* enable innovation. The objective of the thesis has been to highlight not merely the utility of analyzing sub-politics outside of the political system, but to indicate the necessity of attending to tensions between nanosafety and innovation as instrumental to addressing the governance gap of nanotechnology.

These tensions are not confined to the political system of government, nor are they arbitrated solely by 'command and control' between regulation amongst regulators and regulatees. Soft regulation, in its myriad forms, plays a key role in navigating this tension to achieve often dueling regulatory effect. As sub-policy in the Beckian framework, soft regulation however can originate and travel between the institutions of science, industry, civil society and government as it seeks to address and govern the challenges of efficacy, uncertainty and legitimacy. In this manner, the latest shift in the governance of nanosafety and innovation, from approaches of responsible development and Safety by Design to Responsible Research and Innovation and Safe and Sustainable by Design, should be seen in part as an attempt to harmonize and alleviate the tensions in proposals of sub-policy. The governance of safe and sustainable (and) innovation, ascribed to technical harmonization, instead commences with sub-polities that conduct sub-politics to stabilize the power distribution in acting between nanosafety and

innovation. Nanosafety and innovation are not necessarily antithetical, nor are they equivalent. Their relation in context are questions of sub-politics, and politics.

Sub-politics after Beck

So what of sub-politics? For Ulrich Beck, sub-politics is sketched as a concluding discussion to *Risk Society* in prospective cases of medicine, technology policy and industrial automation (1992, 204–23.) The 1990s case of disposing the oil storage buoy *Brent Spar*, and its sub-political campaign by the environmental NGO Greenpeace is perhaps Beck's most notable case study (see 1997a.) Yet, sub-politics remains more of a theoretical curiosity and corollary to *Risk Society*, one that terminates in a triadic translation from political science, in sub-polity, sub-policy and sub-politics.

This thesis has extensively applied the framework of sub-politics directly in its three research questions to demonstrate its continued salience approximately thirty years on. Theoretically, sub-politics is updated for the presiding technoscientific capitalism through the fulcrum of legitimacy that begins in Paper I. Empirically, sub-politics is traced in diverse cases of nanotechnology, from the commitments to responsibility in Paper II and nano-race in Paper III, to the carbon nanotubes debate in Paper IV and perceived credibility of the SIN List in Paper V.

The tracing completed here signals the utility of contemporary conceptualizations of sub-politics, introduced after Beck, along four salient points (see **theoretical framework**.) First, in distinguishing sub-politics between the Aristotelian *poiesis* and *praxis,* de Vries' (2007) study has advocated for an analysis of the "common object" and the "constitution of an association in which this object can circulate." This thesis has posited the object as sub-policy and the association as sub-polity to better approach the "aim for praxis." Holzer and Sørensen (2003) have reframed sub-politics to analyze the sub-political active-passive continuum, second, and typify sub-policies in practice, third, through the stylized modes of buycotting, boycotting, and expertise in the absorption of uncertainty. The thesis has verified the continuum approach, from the active discomforts and commitments in Paper II, to the passive nano-race in Paper III and carbon nanotube debate in Paper IV, and finally to the ambiguous interstices of ChemSec and the SIN List in Paper V. The thesis has emphasized this sub-politics of expertise and proposed uncertainty as a protean problem characterized through multiplication, alongside absorption. Fourth, Bakardjieva (2009) has advocated for subactivism as individual action in the informal ethicalization of everyday life. This

thesis has understood individuals—not in everyday life—but through the variegated public lives of experts and professionals.

Three points of departure

Based on this thesis, there are at least three points of departure through future studies. These can be seen in terms of the three signal contributions, as extensions of (1) the promissory advocate, (2) the multiplication of uncertainty, and (3) the promissory legitimation crisis.

First, future organizational studies could seek to verify the phenomenon and enhance the notion of the promissory advocate. This initial conceptualization is based solely on ChemSec as a case study. Are there others that are not organized as an environmental NGO, or even a governmental organization? Are all three components—innovation intermediary, promissory organization, advocacy—necessary features? While oriented to the future, a key question would be the horizon of the advocate. As expected from a promissory organization, must the horizon align with the strategic instrumentalization of technoscientific capitalism to further enable techno-economic progress? Which types of advocacy could be more successful than others?

Second, the multiplication of uncertainty presents a paradoxical implication. On the one hand, expertise should be expected to absorb uncertainty, even the reflexive practice of absorbing uncertain expertise. On the other, the relative success of such reflexivity is ultimately a matter, not of the *supply-ing* experts, but of the *demand-ing* professionals in this marketplace of certainty in the turn to governance. Experts must lay claim to certainty, at an individual tool-based level like the SIN List, but how much purchase can experts acquire in a many-tools world? It moreover remains unclear to what degree professionals, as opposed to experts, inhabit and reflect upon the multiplication of uncertainty, as this is derived solely from the case of chemical substitution and SIN List. The proposition of a multiplication of uncertainty thus offers a novel departure for future studies of expertise.

Third, the proposed promissory legitimation crisis offers a technique to continue micro-level studies engaging economic sociology with political economy, assisted in this thesis by risk sociology. As explored by Paper I, promissory legitimacy has been outlined by Beckert (2020), in the context of a political economy of neoliberalism and its "exhausted futures." The economic sociology of professionals using the SIN List has been investigated here through the perceived credibility of regulatory fictions. Promises need credibility, while also being susceptible to the risks of reflexivity—both corporeal and

perceptual. The case of nanotechnology has, in a general way, indicated an overarching logic of 'Too Enabling to Fail' where the promises of progress themselves structure technoscientific capitalism, and failure become plausible just as reflexivity becomes a crisis tendency. Are there other dimensions than reflexivity that can become crisis tendencies? As a policy construct, are enabling technologies, read here as nanotechnology, alone in embodying 'Too Enabling to Fail?'

REFERENCES

Alvial-Palavicino, Carla, and Kornelia Konrad. 2019. "The Rise of Graphene Expectations: Anticipatory Practices in Emergent Nanotechnologies." *Futures* 109 (May):192–202. https://doi.org/10/gg4btf.

Amato, Ivan. 1991. "The Apostle of Nanotechnology." *Science* 254 (5036): 1310–11. https://doi.org/10/cmng2j.

Anderson, Ben. 2007. "Hope for Nanotechnology: Anticipatory Knowledge and the Governance of Affect." *Area* 39 (2): 156–65. https://doi.org/10/dw7nc8.

Antonini, Carla, Cornelia Beck, and Carlos Larrinaga. 2020. "Subpolitics and Sustainability Reporting Boundaries. The Case of Working Conditions in Global Supply Chains." *Accounting, Auditing & Accountability Journal* 33 (7): 1535–67. https://doi.org/10/ghxnsm.

Arnaldi, Simone. 2017. "Changing Me Softly: Making Sense of Soft Regulation and Compliance in the Italian Nanotechnology Sector." *NanoEthics* 11 (1): 3–16. https://doi.org/10.1007/s11569-017-0286-5.

Arnaldi, Simone, Andrea Lorenzet, and Federica Russo. 2009. *Technoscience in Progress: Managing the Uncertainty of Nanotechnology*. Amsterdam: IOS Press. http://site.ebrary.com/id/10331648.

Arnall, Alexander, and Douglass Parr. 2005. "Moving the Nanoscience and Technology (NST) Debate Forwards: Short-Term Impacts, Long-Term Uncertainty and the Social Constitution." *Technology in Society* 27 (1): 23–38. https://doi.org/10/ccqjzg.

Arvidsson, Rickard, Max Boholm, Mikael Johansson, and Monica Lindh de Montoya. 2018. "'Just Carbon': Ideas About Graphene Risks by Graphene Researchers and Innovation Advisors." *NanoEthics* 12 (3): 199–210. https://doi.org/10/gfqwmt.

Bakardjieva, Maria. 2009. "Subactivism: Lifeworld and Politics in the Age of the Internet." *The Information Society* 25 (2): 91–104. https://doi.org/10/d4wbr2.

Balbus, John M., Karen Florini, Richard A. Denison, and Scott A. Walsh. 2006. "Protecting Workers and the Environment: An Environmental NGO's Perspective on Nanotechnology." *Journal of Nanoparticle Research* 9 (1): 11–22. https://doi.org/10/d5w53j.

Barben, Daniel, Erik Fisher, Cynthia Selin, and David H Guston. 2008. "Anticipatory Governance of Nanotechnology: Foresight, Engagement, and Integration." In *The Handbook of Science and Technology Studies*, edited by Edward J. Hackett, Olga Amsterdamska, Michael E. Lynch, and Judy Wajcman, 3rd ed., 23. Cambridge, Mass: MIT Press.

Beck, Ulrich. 1992. *Risk Society: Towards a New Modernity*. Theory, Culture & Society. London ; Newbury Park, Calif: Sage Publications.

——. 1997a. "Subpolitics: Ecology and the Disintegration of Institutional Power." *Organization & Environment* 10 (1): 52–65. https://doi.org/10/dcqp3r.

——. 1997b. *The Reinvention of Politics: Rethinking Modernity in the Global Social Order*. Repr. Cambridge: Polity Press.

——. 2018. *The Reinvention of Politics: Rethinking Modernity in the Global Social Order*. John Wiley & Sons.

Beckert, Jens. 2016. *Imagined Futures: Fictional Expectations and Capitalist Dynamics*. Cambridge, Massachusetts: Harvard University Press.

——. 2020. “The Exhausted Futures of Neoliberalism: From Promissory Legitimacy to Social Anomy.” *Journal of Cultural Economy* 13 (3): 318–30. https://doi.org/10/gjrgsg.
——. 2021. “The Firm as an Engine of Imagination: Organizational Prospection and the Making of Economic Futures.” *Organization Theory* 2 (2): 263178772110057. https://doi.org/10/gjpqtt.
——. 2024. “What Makes an Imagined Future Credible?” Discussion Paper 24/5. Cologne, Germany: Max-Planck-Institut für Gesellschaftsforschung.
Bell, Christopher, Ross Garsson, and Jennifer Tomsen. 2013. “Recent Developments in Nanotechnology Standards.” *Nanotechnology Law and Business* 10 (2): 105–13.
Bell, Daniel. 1973. *The Coming of Post-Industrial Society: A Venture in Social Forecasting*. 14. [pr.]. Special Anniversary Edition. New York, NY: Basic Books.
Benn, Suzanne, Paul Brown, and Andrea North-Samardzic. 2009. “A Commentary on Decision-Making and Organisational Legitimacy in the Risk Society.” *Journal of Environmental Management* 90 (4): 1655–62. https://doi.org/10/cpd6g2.
Ben-Porat, Guy. 2009. “Religion and Secularism in Israel: Between Politics and Sub-Politics.” In *Religion and Politics in Europe, the Middle East and North Africa*, edited by Jeffrey Haynes, 0 ed. Routledge. https://doi.org/10.4324/9780203869482.
Bensaude-Vincent, Bernadette. 2006. “Two Cultures of Nanotechnology?” In *Nanotechnology Challenges: Implications for Philosophy, Ethics, and Society*, by Joachim Schummer and Davis Baird, 7–28. WORLD SCIENTIFIC. https://doi.org/10.1142/9789812773975_0002.
——. 2021. “From Nano Backlash to Public Indifference: Some Reflections on French Public Dialogues on Nanotechnology.” *NanoEthics* 15 (2): 191–201. https://doi.org/10/gmw48p.
Bensaude-Vincent, Bernadette, and Arne Hessenbruch. 2004. “Materials Science: A Field about to Explode?” *Nature Materials* 3 (6): 345–47. https://doi.org/10/dzf3sp.
Berube, David M. 2008. “Rhetorical Gamesmanship in the Nano Debates over Sunscreens and Nanoparticles.” *Journal of Nanoparticle Research* 10 (S1): 23–37. https://doi.org/10/bvk6s8.
Birch, Kean. 2013. “The Political Economy of Technoscience: An Emerging Research Agenda.” *Spontaneous Generations: A Journal for the History and Philosophy of Science* 7 (1): 49–61. https://doi.org/10/gg7mth.
——. 2017. “Techno-Economic Assumptions.” *Science as Culture* 26 (4): 433–44. https://doi.org/10/gf38w9.
——, ed. 2020. *Assetization: Turning Things into Assets in Technoscientific Capitalism*. Inside Technology. Cambridge, Massachusetts: The MIT Press.
Boholm, Max, and Rickard Arvidsson. 2016. “A Definition Framework for the Terms Nanomaterial and Nanoparticle.” *NanoEthics* 10 (1): 25–40. https://doi.org/10/f3n954.
Boholm, Max, Rickard Arvidsson, Åsa Boholm, Hervé Corvellec, and Sverker Molander. 2015. “Dis-Ag-Reement: The Construction and Negotiation of Risk in the Swedish Controversy over Antibacterial Silver.” *Journal of Risk Research* 18 (1): 93–110. https://doi.org/10/f2zw9j.
Bowman, Diana M. 2014. “Two Steps Forward, One Step Back: Shaping the Nanotechnologies Landscape Through Regulatory Choice.” In *Nanotechnology Environmental Health and Safety*, 313–35. Elsevier. https://doi.org/10.1016/B978-1-4557-3188-6.00013-X.
Bowman, Diana M., and Graeme A. Hodge. 2008a. “A Big Regulatory Tool-Box for a Small Technology.” *NanoEthics* 2 (2): 193–207. https://doi.org/10/cmgxg6.
Bowman, Diana M, and Graeme A Hodge. 2008b. “‘Governing’ Nanotechnology without Government?” *Science and Public Policy* 35 (7): 475–87. https://doi.org/10/b3x3c2.

Bowman, Diana M., and Graeme A. Hodge. 2009. "Counting on Codes: An Examination of Transnational Codes as a Regulatory Governance Mechanism for Nanotechnologies." *Regulation & Governance* 3 (2): 145–64. https://doi.org/10/dtzdtw.

——. 2010. "Governing Nanotechnologies with Civility." *International Journal of Nanotechnology* 7 (2/3): 224. https://doi.org/10/cgrgsn.

Bowman, Diana M., Graeme A. Hodge, and Peter Binks. 2007. "Are We Really the Prey? Nanotechnology as Science and Science Fiction." *Bulletin of Science, Technology & Society* 27 (6): 435–45. https://doi.org/10/dqm58s.

Bowman, Diana M., and Karinne Ludlow. 2009. "Filling the Information Void: Using Public Registries as a Tool in Nanotechnologies Regulation." *Journal of Bioethical Inquiry* 6 (1): 25–36. https://doi.org/10/frfvq6.

Braun, Maximilian, and Ruth Müller. 2024. "Missed Opportunities for AI Governance: Lessons from ELS Programs in Genomics, Nanotechnology, and RRI." *AI & SOCIETY*, June. https://doi.org/10/gzmpf3.

Broadhead, Lee-Anne, and Sean Howard. 2011. "'Two Cultures,' One Frontier: The Drexler-Smalley Debate on the Limits and Potential of Nanotechnology." *Techné: Research in Philosophy and Technology* 15 (1): 23–35. https://doi.org/10/f2nwks.

Broekhuizen, Pieter van. 2012. "Exposure Limits for Nanoparticles: Report of an International Workshop on Nano Reference Values." *The Annals of Occupational Hygiene*, June. https://doi.org/10/g8x7md.

Broekhuizen, Pieter van, and Bärbel Dorbeck-Jung. 2013. "Exposure Limit Values for Nanomaterials—Capacity and Willingness of Users to Apply a Precautionary Approach." *Journal of Occupational and Environmental Hygiene* 10 (1): 46–53. https://doi.org/10/g8mhcg.

Broekhuizen, Pieter van, and Lucas Reijnders. 2011. "Building Blocks for a Precautionary Approach to the Use of Nanomaterials: Positions Taken by Trade Unions and Environmental NGOs in the European Nanotechnologies Debate." *Risk Analysis* 31 (10): 1646–57. https://doi.org/10/dxmzcc.

Buizer, Marleen, and Esther Turnhout. 2011. "Text, Talk, Things, and the Subpolitics of Performing Place." *Geoforum* 42 (5): 530–38. https://doi.org/10/fq6mmf.

Burri, Regula Valérie. 2007. "Deliberating Risks Under Uncertainty: Experience, Trust, and Attitudes in a Swiss Nanotechnology Stakeholder Discussion Group." *NanoEthics* 1 (2): 143–54. https://doi.org/10/dt3kdr.

Caldeira, C., I. Garmendia Aguirre, D. Tosches, L. Mancini, E. Abbate, R. Farcal, D. Lipsa, et al. 2023. "Safe and Sustainable by Design Chemicals and Materials: Application of the SSbD Framework to Case Studies." Luxembourg: Publications Office. https://data.europa.eu/doi/10.2760/329423.

Caldeira, C., R. Farcal, C. Moretti, L. Mancini, H. Rauscher, K. Rasmussen, J. Riego Sintes, and S. Sala. 2022. "Safe and Sustainable by Design Chemicals and Materials: Review of Safety and Sustainability Dimensions, Aspects, Methods, Indicators, and Tools." Luxembourg: Publications Office of the European Union. https://data.europa.eu/doi/10.2760/879069.

Caldeira, Carla, Lucian R. Farcal, Irantzu Garmendia, Lucia Mancini, Davide Tosches, Antonio Amelio, Kirsten Rasmussen, Hubert Rauscher, Juan Riego Sintes, and Serenella Sala. 2022. "Safe and Sustainable by Design Chemicals and Materials: Framework for the Definition of Criteria and Evaluation Procedure for Chemicals and Materials." Luxembourg: Publications Office of the European Union. https://data.europa.eu/doi/10.2760/487955.

Callon, Michel. 1984. “Some Elements of a Sociology of Translation: Domestication of the Scallops and the Fishermen of St Brieuc Bay.” *The Sociological Review* 32 (1_suppl): 196–233. https://doi.org/10/gc6wfc.
Cefic. 2024. “SAFE AND SUSTAINABLE- BY-DESIGN: A GUIDANCE TO UNLEASH THE TRANSFORMATIVE POWER OF INNOVATION.” Cefic.
——. 2025. “2024 Facts and Figures of the European Chemical Industry.” The European Chemical Industry Council, AISBL. https://cefic.org/a-pillar-of-the-european-economy/facts-and-figures-of-the-european-chemical-industry/.
Chadwick, Rachelle. 2021. “On the Politics of Discomfort.” *Feminist Theory* 22 (4): 556–74. https://doi.org/10.1177/1464700120987379.
Chan, Raymond K.H. 2008. “Risk, Reflexivity and Sub-Politics: Environmental Politics in Hong Kong.” *Asian Journal of Political Science* 16 (3): 260–75. https://doi.org/10/dxhm3k.
ChemSec. 2023. “Financial-Statement 2023.” https://chemsec.org/app/uploads/2024/05/2023-Financial-Statement.pdf.
Coenen, Christopher. 2022. “Against Bureaucrapitalism: A Response to Shanley and Colleagues.” *Journal of Responsible Innovation*, March, 1–4. https://doi.org/10.1080/23299460.2022.2055993.
Cohen, Joshua B., and Robert Gianni. 2023. “Democratic Experimentation with Responsibility: A Pragmatist Approach to Responsible Research and Innovation.” In *Putting Responsible Research and Innovation into Practice*, edited by Vincent Blok, 40:57–77. Library of Ethics and Applied Philosophy. Cham: Springer International Publishing. https://doi.org/10.1007/978-3-031-14710-4_4.
Collingridge, David. 1982. *The Social Control of Technology*. Repr. London: Pinter.
Collins, H.M., and Robert Evans. 2002. “The Third Wave of Science Studies: Studies of Expertise and Experience.” *Social Studies of Science* 32 (2): 235–96. https://doi.org/10/cbrv4z.
Colvin, Vicki L. 2003. “The Potential Environmental Impact of Engineered Nanomaterials.” *Nature Biotechnology* 21 (10): 1166–70. https://doi.org/10/b4srhp.
Cook, Guy, Elisa Pieri, and Peter T. Robbins. 2004. “‘The Scientists Think and the Public Feels’: Expert Perceptions of the Discourse of GM Food.” *Discourse & Society* 15 (4): 433–49. https://doi.org/10/crzq72.
Coria, Jessica, Erik Kristiansson, and Mikael Gustavsson. 2022. “Economic Interests Cloud Hazard Reductions in the European Regulation of Substances of Very High Concern.” *Nature Communications* 13 (1): 6686. https://doi.org/10.1038/s41467-022-34492-2.
Cramer, Katharina C., and Nicolas V. Rüffin. 2025. “The EUropeanisation of Research Infrastructure Policy.” *Minerva* 63 (1): 45–68. https://doi.org/10/g8tqz2.
Davies, Sarah R., Cecilie Glerup, and Maja Horst. 2014. “On Being Responsible: Multiplicity in Responsible Development.” In *Responsibility in Nanotechnology Development*, edited by Simone Arnaldi, Arianna Ferrari, Paolo Magaudda, and Francesca Marin, 13:143–59. The International Library of Ethics, Law and Technology. Dordrecht: Springer Netherlands. https://doi.org/10.1007/978-94-017-9103-8_9.
Davies, Sarah R., and Cynthia Selin. 2012. “Energy Futures: Five Dilemmas of the Practice of Anticipatory Governance.” *Environmental Communication* 6 (1): 119–36. https://doi.org/10/g82386.
De Vries, Gerard. 2007. “What Is Political in Sub-Politics?: How Aristotle Might Help STS.” *Social Studies of Science* 37 (5): 781–809. https://doi.org/10/c2zhdv.

Delemarle, Aurélie, and Harald Throne-Holst. 2013. "The Role Of Standardization in the Shaping of a Vision for Nanotechnology." *International Journal of Innovation and Technology Management* 10 (02): 1340005. https://doi.org/10/gn6qbd.

Delgado, Ana, Kamilla Lein Kjølberg, and Fern Wickson. 2011. "Public Engagement Coming of Age: From Theory to Practice in STS Encounters with Nanotechnology." *Public Understanding of Science* 20 (6): 826–45. https://doi.org/10.1177/0963662510363054.

Doorn, Neelke. 2013. "Wide Reflective Equilibrium as a Normative Model for Responsible Governance." *NanoEthics* 7 (1): 29–43. https://doi.org/10/gjvm8z.

Dorbeck-Jung, Bärbel, and Clare Shelley-Egan. 2013. "Meta-Regulation and Nanotechnologies: The Challenge of Responsibilisation Within the European Commission's Code of Conduct for Responsible Nanosciences and Nanotechnologies Research." *NanoEthics* 7 (1): 55–68. https://doi.org/10.1007/s11569-013-0172-8.

Doubleday, Robert. 2007a. "Risk, Public Engagement and Reflexivity: Alternative Framings of the Public Dimensions of Nanotechnology." *Health, Risk & Society* 9 (2): 211–27. https://doi.org/10/cbxv89.

——. 2007b. "The Laboratory Revisited: Academic Science and the Responsible Development of Nanotechnology." *NanoEthics* 1 (2): 167–76. https://doi.org/10/cjbt84.

Drexler, Eric. 1986. *Engines of Creation: The Coming Era of Nanotechnology*. Anchor.

Drexler, K. Eric. 2004. "Nanotechnology: From Feynman to Funding." *Bulletin of Science, Technology & Society* 24 (1): 21–27. https://doi.org/10.1177/0270467604263113.

Dunphy Guzmán, Katherine A., Margaret R. Taylor, and Jillian F. Banfield. 2006. "Environmental Risks of Nanotechnology: National Nanotechnology Initiative Funding, 2000—2004." *Environmental Science & Technology* 40 (5): 1401–7. https://doi.org/10/bbttxd.

Ebeling, Mary F. E. 2008. "Mediating Uncertainty: Communicating the Financial Risks of Nanotechnologies." *Science Communication* 29 (3): 335–61. https://doi.org/10/d26q74.

Eden, S. 1999. "'We Have the Facts'—How Business Claims Legitimacy in the Environmental Debate." *Environment and Planning A: Economy and Space* 31 (7): 1295–1309. https://doi.org/10/bb59sk.

Ehnert, Tanja. 2015. "The Legitimacy of New Risk Governance—A Critical View in Light of the EU's Approach to Nanotechnologies in Food." *European Law Journal* 21 (1): 44–67. https://doi.org/10/g8zcxb.

Eide, Martin, and Graham Knight. 1999. "Public/Private Service: Service Journalism and the Problems of Everyday Life." *European Journal of Communication* 14 (4): 525–47. https://doi.org/10/b9c6jg.

Eisler, Matthew N. 2013. "'The Ennobling Unity of Science and Technology': Materials Sciences and Engineering, the Department of Energy, and the Nanotechnology Enigma." *Minerva* 51 (2): 225–51. https://doi.org/10/f4zjjz.

Engeman, Cassandra D., Lynn Baumgartner, Benjamin M. Carr, Allison M. Fish, John D. Meyerhofer, Terre A. Satterfield, Patricia A. Holden, and Barbara Herr Harthorn. 2013. "The Hierarchy of Environmental Health and Safety Practices in the U.S. Nanotechnology Workplace." *Journal of Occupational and Environmental Hygiene* 10 (9): 487–95. https://doi.org/10/g8z68h.

Engi, D., and J. Glicken. 1995. "The Vital Issues Process: Strategic Planning for a Changing World." SAND-95-0845. Albuquerque, NM, United States: Sandia Labs. https://doi.org/10.2172/89508.

Erhardt, David. 2003. "Not-so-New Technology." *Nature Materials* 2 (8): 509–10. https://doi.org/10/cmw4vd.

ETC Group. 2003. “The Big Down: Atomtech: Technologies Converging at the Nano-Scale.” Winnipeg.
European Chemicals Agency. 2022. *Study of the EU Market for Nanomaterials, Including Substances, Uses, Volumes and Key Operators*. LU: Publications Office. https://data.europa.eu/doi/10.2823/680824.
European Commission. 2001. *European Governance: A White Paper*. Publications Office of the European Union. https://op.europa.eu/en/publication-detail/-/publication/11c3e337-9cf5-4603-a518-cacb77207e3b.
——. 2004. “COMMUNICATION FROM THE COMMISSION Towards a European Strategy for Nanotechnology.” COM(2004) 338 final. Brussels: Publications Office of the European Union. https://op.europa.eu/en/publication-detail/-/publication/0c0b7b1f-bd96-43e5-8f63-b26b2398b908/language-en.
——. 2006. *Regulation (EC) No 1907/2006 of the European Parliament and of the Council of 18 December 2006 Concerning the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH), Establishing a European Chemicals Agency, Amending Directive 1999/45/EC and Repealing Council Regulation (EEC) No 793/93 and Commission Regulation (EC) No 1488/94 as Well as Council Directive 76/769/EEC and Commission Directives 91/155/EEC, 93/67/EEC, 93/105/EC and 2000/21/EC*. http://data.europa.eu/eli/reg/2006/1907/2024-12-18/eng.
——. 2008a. “COMMISSION RECOMMENDATION of 7 February 2008 on a Code of Conduct for Responsible Nanosciences and Nanotechnologies Research.” *OJ L*. Vol. 345. Brussels: European Commission. https://eur-lex.europa.eu/eli/reco/2008/345/oj/eng.
——. 2008b. *Regulation (EC) No 1272/2008 of the European Parliament and of the Council of 16 December 2008 on Classification, Labelling and Packaging of Substances and Mixtures, Amending and Repealing Directives 67/548/EEC and 1999/45/EC, and Amending Regulation (EC) No 1907/2006 (Text with EEA Relevance)*. http://data.europa.eu/eli/reg/2008/1272/2025-02-01/eng.
——. 2021. *Better Regulation: Joining Forces to Make Better Laws*. https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52021DC0219.
——. 2022. *Commission Recommendation (EU) 2022/2510 of 8 December 2022 Establishing a European Assessment Framework for ‘Safe and Sustainable by Design’ Chemicals and Materials*. *OJ L*. Vol. 325. http://data.europa.eu/eli/reco/2022/2510/oj/eng.
Eurostat. 2024. “Production and Consumption of Chemicals by Hazard Class.” Eurostat. https://doi.org/10.2908/ENV_CHMHAZ.
Falkner, Robert, and Nico Jaspers. 2012. “Regulating Nanotechnologies: Risk, Uncertainty and the Global Governance Gap.” *Global Environmental Politics* 12 (1): 30–55. https://doi.org/10/fzjsrk.
Feitshans, Ilise L. 2021. “Emerging Nanoregulations: Zapping the Mythical Absence of Nanotechnology Law.” In *Ethics in Nanotechnology*, edited by Marcel Van De Voorde and Gunjan Jeswani, 297–310. De Gruyter. https://doi.org/10.1515/9783110719932-012.
Ferrari, Arianna. 2010. “Developments in the Debate on Nanoethics: Traditional Approaches and the Need for New Kinds of Analysis.” *NanoEthics* 4 (1): 27–52. https://doi.org/10/dgz8qm.
Ferrari, Arianna, and Alfred Nordmann. 2010. “Beyond Conversation: Some Lessons for Nanoethics.” *NanoEthics* 4 (2): 171–81. https://doi.org/10/cbjfgt.
Feynman, Richard P. 1960. “There’s Plenty of Room at the Bottom.” *Engineering and Science* 23 (5): 22–36.

Foladori, Guillermo. 2017. "Occupational and Environmental Safety Standards in Nanotechnology: International Organization for Standardization, Latin America and Beyond." *The Economic and Labour Relations Review* 28 (4): 538–54. https://doi.org/10/g8zrft.

Forsberg, Ellen-Marie. 2012. "Standardisation in the Field of Nanotechnology: Some Issues of Legitimacy." *Science and Engineering Ethics* 18 (4): 719–39. https://doi.org/10/c7n5cs.

Fourcade, Marion, Jens Beckert, Neil Fligstein, and Bruce G Carruthers. 2023. "Reflections on the Field of Socio-Economics." *Socio-Economic Review* 21 (2): 703–20. https://doi.org/10/g8643f.

Gallo, Jason. 2009. "The Discursive and Operational Foundations of the National Nanotechnology Initiative in the History of the National Science Foundation." *Perspectives on Science* 17 (2): 174–211. https://doi.org/10/dxtmxx.

Glerup, Cecilie, Sarah R. Davies, and Maja Horst. 2017. "'Nothing Really Responsible Goes on Here': Scientists' Experience and Practice of Responsibility." *Journal of Responsible Innovation* 4 (3): 319–36. https://doi.org/10/ggjtnj.

Goebelbecker, Joel, and Eike Albrecht. 2016. "Soft Regulation Follows Hard Risk Management-European Food Sector on Nanotechnologies." *European Food and Feed Law Review* 11 (2): 107–18.

Goorden, Lieve, Michiel Van Oudheusden, Johan Evers, and Marian Deblonde. 2008. "Lose One Another … and Find One Another in Nanospace. 'Nanotechnologies for Tomorrow's Society: A Case for Reflective Action Research in Flanders (NanoSoc).'" *NanoEthics* 2 (3): 213–30. https://doi.org/10/c6cbd5.

Gottardo, Stefania, Agnieszka Mech, Jana Drbohlavová, Aleksandra Małyska, Søren Bøwadt, Juan Riego Sintes, and Hubert Rauscher. 2021. "Towards Safe and Sustainable Innovation in Nanotechnology: State-of-Play for Smart Nanomaterials." *NanoImpact* 21 (January):100297. https://doi.org/10/gh7r4t.

Gram-Hanssen, Kirsten. 2000. "Local Agenda 21: Traditional *Gemeinschaft* or Late-Modern Subpolitics?" *Journal of Environmental Policy & Planning* 2 (3): 225–35. https://doi.org/10/dk8xq7.

Grieger, K.D., F. Wickson, H.B. Andersen, and O. Renn. 2012. "Improving Risk Governance of Emerging Technologies through Public Engagement: The Neglected Case of Nano-Remediation?" *Australian Journal of Emerging Technologies and Society* 10 (1): 61–78.

Grieger, Khara D., Ashton W. Merck, Maude Cuchiara, Andrew R. Binder, Adam Kokotovich, Christopher L. Cummings, and Jennifer Kuzma. 2021. "Responsible Innovation of Nano-Agrifoods: Insights and Views from U.S. Stakeholders." *NanoImpact* 24 (October):100365. https://doi.org/10/gntbpg.

Groenewold, Monique, Eric A.J. Bleeker, Cornelle W. Noorlander, Adriënne J.A.M. Sips, Margriet Van Der Zee, Robert J. Aitken, James H. Baker, et al. 2024. "Governance of Advanced Materials: Shaping a Safe and Sustainable Future." *NanoImpact* 35 (July):100513. https://doi.org/10/gwc9vb.

Groves, Chris, Lori Frater, Robert Lee, and Elen Stokes. 2011. "Is There Room at the Bottom for CSR? Corporate Social Responsibility and Nanotechnology in the UK." *Journal of Business Ethics* 101 (4): 525–52. https://doi.org/10/bzw8ns.

Groves, Christopher. 2009. "Nanotechnology, Contingency and Finitude." *NanoEthics* 3 (1): 1–16. https://doi.org/10/bd73ws.

——. 2011. "Public Engagement and Nanotechnology in the UK: Restoring Trust or Building Robustness?" *Science and Public Policy* 38 (10): 783–93. https://doi.org/10/fzwrz7.

Grunwald, Armin. 2005. "Nanotechnology — A New Field of Ethical Inquiry?" *Science and Engineering Ethics* 11 (2): 187–201. https://doi.org/10/bfbg46.
——. 2010. "From Speculative Nanoethics to Explorative Philosophy of Nanotechnology." *NanoEthics* 4 (2): 91–101. https://doi.org/10/dqrcpc.
——. 2014. "Responsible Research and Innovation: An Emerging Issue in Research Policy Rooted in the Debate on Nanotechnology." In *Responsibility in Nanotechnology Development*, edited by Simone Arnaldi, Arianna Ferrari, Paolo Magaudda, and Francesca Marin, 13:191–205. The International Library of Ethics, Law and Technology. Dordrecht: Springer Netherlands. https://doi.org/10.1007/978-94-017-9103-8_12.
Habermas, Jürgen. 1975. *Legitimation Crisis*. Translated by Thomas A. McCarthy. Boston, Mass: Beacon Press.
Hamlin, Christopher. 2007. "STS: Where the Marxist Critique of Capitalist Science Goes to Die?" *Science as Culture* 16 (4): 467–74. https://doi.org/10/bvtnw4.
Hansen, Steffen Foss, and Anders Baun. 2012. "When Enough Is Enough." *Nature Nanotechnology* 7 (7): 409–11. https://doi.org/10/gf64q4.
Hansen, Steffen Foss, Oliver Foss Hessner Hansen, and Maria Bille Nielsen. 2020. "Advances and Challenges towards Consumerization of Nanomaterials." *Nature Nanotechnology* 15 (12): 964–65. https://doi.org/10/ghnj4g.
Hansen, Steffen Foss, Laura Roverskov Heggelund, Pau Revilla Besora, Aiga Mackevica, Alessio Boldrin, and Anders Baun. 2016. "Nanoproducts – What Is Actually Available to European Consumers?" *Environmental Science: Nano* 3 (1): 169–80. https://doi.org/10/ghcmr7.
Hansen, Steffen Foss, Keld Alstrup Jensen, and Anders Baun. 2014. "NanoRiskCat: A Conceptual Tool for Categorization and Communication of Exposure Potentials and Hazards of Nanomaterials in Consumer Products." *Journal of Nanoparticle Research* 16 (1): 2195. https://doi.org/10/ghphvm.
Hansen, Steffen Foss, Britt H. Larsen, Stig I. Olsen, and Anders Baun. 2007. "Categorization Framework to Aid Hazard Identification of Nanomaterials." *Nanotoxicology* 1 (3): 243–50. https://doi.org/10/dc6qtb.
Hansen, Steffen Foss, and Anna Lennquist. 2020. "Carbon Nanotubes Added to the SIN List as a Nanomaterial of Very High Concern." *Nature Nanotechnology* 15 (1): 3–4. https://doi.org/10/ggq4mw.
Heltzel, Anouk, J. W. Schuijer, W.L. Willems, F. Kupper, and J. E. W. Broerse. 2022. "'There Is Nothing Nano-Specific Here': A Reconstruction of the Different Understandings of Responsiveness in Responsible Nanotechnology Innovation." *Journal of Responsible Innovation* 9 (2): 173–95. https://doi.org/10/gshppf.
Héritier, Adrienne, and Dirk Lehmkuhl. 2008. "The Shadow of Hierarchy and New Modes of Governance." *Journal of Public Policy* 28 (1): 1–17. https://doi.org/10/dsmrnd.
Hess, David J. 2010. "Environmental Reform Organizations and Undone Science in the United States: Exploring the Environmental, Health, and Safety Implications of Nanotechnology." *Science as Culture* 19 (2): 181–214. https://doi.org/10/d2hwmv.
Hey, Christian, Klaus Jacob, and Axel Volkery. 2007. "Better Regulation by New Governance Hybrids? Governance Models and the Reform of European Chemicals Policy." *Journal of Cleaner Production* 15 (18): 1859–74. https://doi.org/10/cmt98q.
Holzer, Boris, and Mads P. Sørensen. 2003. "Rethinking Subpolitics: Beyond the 'Iron Cage' of Modern Politics?" *Theory, Culture & Society* 20 (2): 79–102. https://doi.org/10/ddc4g9.

Hong, Hyunjoo, Claudia Som, and Bernd Nowack. 2023. "Development of a Benefit Assessment Matrix for Nanomaterials and Nano-Enabled Products—Toward Safe and Sustainable by Design." *Sustainability* 15 (3): 2321. https://doi.org/10/gs7hgj.

Hove, Lilian van, and Fern Wickson. 2017. "Responsible Research Is Not Good Science: Divergences Inhibiting the Enactment of RRI in Nanosafety." *NanoEthics* 11 (3): 213–28. https://doi.org/10/gg2kr5.

Hoven, Jeroen van den. 2022. "Responsibility and Innovation." *Journal of Responsible Innovation*, March, 1–5. https://doi.org/10.1080/23299460.2022.2050570.

Howells, Jeremy. 2006. "Intermediation and the Role of Intermediaries in Innovation." *Research Policy* 35 (5): 715–28. https://doi.org/10/dvh8bd.

Hristozov, Danail, Elena Badetti, Paolo Bigini, Andrea Brunelli, Susan Dekkers, Luisa Diomede, Shareen H. Doak, et al. 2024. "Next Generation Risk Assessment Approaches for Advanced Nanomaterials: Current Status and Future Perspectives." *NanoImpact* 35 (July):100523. https://doi.org/10/gt747h.

Huang, Can, Ad Notten, and Nico Rasters. 2011. "Nanoscience and Technology Publications and Patents: A Review of Social Science Studies and Search Strategies." *The Journal of Technology Transfer* 36 (2): 145–72. https://doi.org/10/dks8fv.

Isaacs, Jacqueline A., Carol Lynn Alpert, Matthew Bates, Christopher J. Bosso, Matthew J. Eckelman, Igor Linkov, and William C. Walker. 2015. "Engaging Stakeholders in Nano-EHS Risk Governance." *Environment Systems and Decisions* 35 (1): 24–28. https://doi.org/10/gg3w5k.

Jansma, Sikke R., Anne M. Dijkstra, and Menno D. T. de Jong. 2021a. "How Can I Contribute? Citizen Engagement in the Development of Nanotechnology for Health." *NanoEthics* 15 (3): 211–27. https://doi.org/10.1007/s11569-021-00403-w.

Jansma, Sikke R., Anne M. Dijkstra, and Menno D.T. de Jong. 2021b. "Co-Creation in Support of Responsible Research and Innovation: An Analysis of Three Stakeholder Workshops on Nanotechnology for Health." *Journal of Responsible Innovation*, November, 1–21. https://doi.org/10/gntbck.

Jasanoff, Sheila. 2003. "Breaking the Waves in Science Studies: Comment on H.M. Collins and Robert Evans, `The Third Wave of Science Studies'." *Social Studies of Science* 33 (3): 389–400. https://doi.org/10/bmwd7w.

Jensen, Eric. 2012. "Mediating Subpolitics in US and UK Science News." *Public Understanding of Science* 21 (1): 68–83. https://doi.org/10/b45trb.

Johansson, Mikael, and Åsa Boholm. 2017. "Scientists' Understandings of Risk of Nanomaterials: Disciplinary Culture Through the Ethnographic Lens." *NanoEthics* 11 (3): 229–42. https://doi.org/10/gcjm9n.

Johnson, Ann. 2004. "The End of Pure Science: Science Policy from Bayh-Dole to the NNI." In *Discovering the Nanoscale*, edited by Davis Baird, Alfred Nordmann, and Joachim Schummer, 217–30. Amsterdam ; Washington, DC: IOS Press.

Joly, Pierre-Benoit, and Alain Kaufmann. 2008. "Lost in Translation? The Need for 'Upstream Engagement' with Nanotechnology on Trial." *Science as Culture* 17 (3): 225–47. https://doi.org/10/cs6r9d.

Jotterand, Fabrice. 2006. "The Politicization of Science and Technology: Its Implications for Nanotechnology." *Journal of Law, Medicine & Ethics* 34 (4): 658–66. https://doi.org/10/fdh2n4.

Joy, Bill. 2000. "Why the Future Doesn't Need Us." *Wired*, April 1, 2000. https://www.wired.com/2000/04/joy-2/.

Jürgens, Björn, and Victor Herrero-Solana. 2017. "Monitoring Nanotechnology Using Patent Classifications: An Overview and Comparison of Nanotechnology Classification Schemes." *Journal of Nanoparticle Research* 19 (4): 151. https://doi.org/10/f96dkv.

Kaplan, Sarah, and Joanna Radin. 2011. "Bounding an Emerging Technology: Para-Scientific Media and the Drexler-Smalley Debate about Nanotechnology." *Social Studies of Science* 41 (4): 457–85. https://doi.org/10/c25v35.

Katz, Evie, Fiona Solomon, Wendy Mee, and Roy Lovel. 2009. "Evolving Scientific Research Governance in Australia: A Case Study of Engaging Interested Publics in Nanotechnology Research." *Public Understanding of Science* 18 (5): 531–45. https://doi.org/10/dgpc9v.

Kearnes, Matthew, and Brian Wynne. 2007. "On Nanotechnology and Ambivalence: The Politics of Enthusiasm." *NanoEthics* 1 (2): 131–42. https://doi.org/10/cxgn4s.

Keller, Arturo A., and Anastasiya Lazareva. 2013. "Predicted Releases of Engineered Nanomaterials: From Global to Regional to Local." *Environmental Science & Technology Letters* 1 (1): 65–70. https://doi.org/10/gf66c7.

Kelty, Christopher M. 2009. "Beyond Implications and Applications: The Story of 'Safety by Design.'" *NanoEthics* 3 (2): 79–96. https://doi.org/10/fjnzvt.

Kera, Denisa. 2012. "NanoŠmano Lab in Ljubljana: Disruptive Prototypes and Experimental Governance of Nanotechnologies in the Hackerspaces." *Journal of Science Communication* 11 (04): C03. https://doi.org/10/gmp328.

Kermisch, Céline. 2012. "Do New Ethical Issues Arise at Each Stage of Nanotechnological Development?" *NanoEthics* 6 (1): 29–37. https://doi.org/10/bdmb2k.

Kica, Evisa, and Diana M Bowman. 2012. "REGULATION BY MEANS OF STANDARDIZATION: KEY LEGITIMACY ISSUES OF HEALTH AND SAFETY NANOTECHNOLOGY STANDARDS." *Jurimetrics* 53 (1): 11–56.

Kivijärvi, Antti. 2010. "Local Youth Work as Subpolitics of Multiculturalism: Professional Educators Constructing New Rationales in Eastern Finland?" *Studies in Ethnicity and Nationalism* 10 (2): 204–20. https://doi.org/10/dns2bg.

Kjølberg, Kamilla Lein, and Roger Strand. 2011. "Conversations About Responsible Nanoresearch." *NanoEthics* 5 (1): 99–113. https://doi.org/10/ffh3b6.

Klaine, Stephen J., Pedro J. J. Alvarez, Graeme E. Batley, Teresa F. Fernandes, Richard D. Handy, Delina Y. Lyon, Shaily Mahendra, Michael J. McLaughlin, and Jamie R. Lead. 2008. "Nanomaterials in the Environment: Behavior, Fate, Bioavailability, and Effects." *Environmental Toxicology and Chemistry* 27 (9): 1825–51. https://doi.org/10/d7mdcf.

Kleinman, Daniel Lee, Jason A. Delborne, and Ashley A. Anderson. 2011. "Engaging Citizens: The High Cost of Citizen Participation in High Technology." *Public Understanding of Science* 20 (2): 221–40. https://doi.org/10/ct4575.

Knight, Graham, and Josh Greenberg. 2002. "Promotionalism and Subpolitics: Nike and Its Labor Critics." *Management Communication Quarterly* 15 (4): 541–70. https://doi.org/10/cf8ghb.

Köhler, Andreas R., and Claudia Som. 2008. "Environmental and Health Implications of Nanotechnology—Have Innovators Learned the Lessons from Past Experiences?" *Human and Ecological Risk Assessment: An International Journal* 14 (3): 512–31. https://doi.org/10/fnkbz5.

Krabbenborg, Lotte. 2013. "DuPont and Environmental Defense Fund Co-Constructing a Risk Framework for Nanoscale Materials: An Occasion to Reflect on Interaction Processes in a Joint Inquiry." *NanoEthics* 7 (1): 45–54. https://doi.org/10/g825d8.

——. 2020. “Deliberation on the Risks of Nanoscale Materials: Learning from the Partnership between Environmental NGO EDF and Chemical Company DuPont.” *Policy Studies* 41 (4): 372–91. https://doi.org/10/gn2c4m.

Kulinowski, Kristen. 2004. “Nanotechnology: From ‘Wow’ to ‘Yuck’?” *Bulletin of Science, Technology & Society* 24 (1): 13–20. https://doi.org/10.1177/0270467604263112.

Kyle, Renee, and Susan Dodds. 2009. “Avoiding Empty Rhetoric: Engaging Publics in Debates About Nanotechnologies.” *Science and Engineering Ethics* 15 (1): 81–96. https://doi.org/10/b943kp.

Lash, Scott, and Brian Wynne. 1992. “Introduction.” In *Risk Society: Towards a New Modernity*, by Ulrich Beck. Theory, Culture & Society. London ; Newbury Park, Calif: Sage Publications.

Latour, Bruno. 2003. “Is Re-Modernization Occurring - And If So, How to Prove It?: A Commentary on Ulrich Beck.” *Theory, Culture & Society* 20 (2): 35–48. https://doi.org/10/bcb6kb.

Laurent, Brice. 2012. “Responsible Agencements: Constructing Markets for Nanotechnology through the European Regulation.” *Nanotechnology Law & Business* 9 (3): 267–82.

——. 2013. “Nanomaterials in Political Life: In the Democracies of Nanotechnology.” In *Nanomaterials: A Danger or a Promise?*, edited by Roberta Brayner, Fernand Fiévet, and Thibaud Coradin, 379–99. London: Springer London. https://doi.org/10.1007/978-1-4471-4213-3_15.

——. 2017. “Mobilizing against, Mobilizing within Nanotechnology.” In *Democratic Experiments*, by Brice Laurent, 151–78. The MIT Press. https://doi.org/10.7551/mitpress/10580.003.0011.

Le Coze, Jean-Christophe, and Benoît Journé, eds. 2024. *The Regulator–Regulatee Relationship in High-Hazard Industry Sectors: New Actors and New Viewpoints in a Conservative Landscape*. SpringerBriefs in Applied Sciences and Technology. Cham: Springer Nature Switzerland. https://doi.org/10.1007/978-3-031-49570-0.

Lee, Robert, and P.D. Jose. 2008. “Self-Interest, Self-Restraint and Corporate Responsibility for Nanotechnologies: Emerging Dilemmas for Modern Managers.” *Technology Analysis & Strategic Management* 20 (1): 113–25. https://doi.org/10/fn4tds.

Lee, Woochang, and Hyomin Kim. 2022. “The Politics and Sub-Politics of Mad Cow Disease in South Korea.” *East Asian Science, Technology and Society: An International Journal* 16 (4): 486–508. https://doi.org/10/g5xkk7.

Lennquist, Anna, Jonatan Kleimark, Hans Peter H. Arp, and Sarah E. Hale. 2024. “Facilitating the Market Transition Away from Persistent and Mobile Substances: A Report on Tools Developed by ChemSec in the ZeroPM Project: SIN List, Marketplace and the PFAS Guide.” *Environmental Sciences Europe* 36 (1): 2. https://doi.org/10/gtcv7b.

Lindgren, Simon, and Jessica Linde. 2012. “The Subpolitics of Online Piracy: A Swedish Case Study.” *Convergence: The International Journal of Research into New Media Technologies* 18 (2): 143–64. https://doi.org/10/f24dqk.

Lindquist, Eric, Katrina N. Mosher-Howe, and Xinsheng Liu. 2010. “Nanotechnology . . . What Is It Good For? (Absolutely Everything): A Problem Definition Approach: Nanotechnology . . . What Is It Good For?” *Review of Policy Research* 27 (3): 255–71. https://doi.org/10/dtxfs2.

Loon, Joost van. 2007. “Governmentality and the Subpolitics of Teenage Sexual Risk Behaviour.” In *Health, Risk and Vulnerability*. London: Routledge.

Lyons, Kristen, and James Whelan. 2010. "Community Engagement to Facilitate, Legitimize and Accelerate the Advancement of Nanotechnologies in Australia." *NanoEthics* 4 (1): 53–66. https://doi.org/10/djm622.

Lyotard, Jean-François. 1984. *The Postmodern Condition: A Report on Knowledge*. Theory and History of Literature, v. 10. Minneapolis: University of Minnesota Press.

Macnaghten, Phil, and Julia S. Guivant. 2011. "Converging Citizens? Nanotechnology and the Political Imaginary of Public Engagement in Brazil and the United Kingdom." *Public Understanding of Science* 20 (2): 207–20. https://doi.org/10/dfs29x.

Macq, Hadrien, Élise Tancoigne, and Bruno J. Strasser. 2020. "From Deliberation to Production: Public Participation in Science and Technology Policies of the European Commission (1998–2019)." *Minerva*, April. https://doi.org/10/ggwsq2.

Malakar, Yuwan, and Justine Lacey. 2023. "On the Interconnected Nature of Risk and Responsibility in the Research and Development of New and Emerging Technologies." *Risk Analysis*, September, risa.14229. https://doi.org/10/gtptnf.

Malloy, Timothy F. 2011. "Nanotechnology Regulation: A Study in Claims Making." *ACS Nano* 5 (1): 5–12. https://doi.org/10/c6bvq8.

Malsch, Ineke, Martin Mullins, Elena Semenzin, Alex Zabeo, Danail Hristozov, and Antonio Marcomini. 2018. "Decision Support for International Agreements Regulating Nanomaterials." *NanoEthics* 12 (1): 39–54. https://doi.org/10/g4h4mx.

Marchant, Gary E. 2011. "Addressing the Pacing Problem." In *The Growing Gap Between Emerging Technologies and Legal-Ethical Oversight*, edited by Gary E. Marchant, Braden R. Allenby, and Joseph R. Herkert, 7:199–205. The International Library of Ethics, Law and Technology. Dordrecht: Springer Netherlands. https://doi.org/10.1007/978-94-007-1356-7_13.

——. 2014. "'Soft Law' Mechanisms for Nanotechnology: Liability and Insurance Drivers." *Journal of Risk Research* 17 (6): 709–19. https://doi.org/10/g8zcxk.

Marres, Noortje, and Javier Lezaun. 2011. "Materials and Devices of the Public: An Introduction." *Economy and Society* 40 (4): 489–509. https://doi.org/10/c7fpvg.

Maynard, Andrew. 2011. "Don't Define Nanomaterials." *Nature* 475 (7354): 31–31. https://doi.org/10/bdjfpz.

McCarthy, Elise, and Christopher Kelty. 2010. "Responsibility and Nanotechnology." *Social Studies of Science* 40 (3): 405–32. https://doi.org/10/d3q4zj.

Mcgovern, Charles. 2016. "INSCX Exchange: The Hub Approach to Self-Regulation in Support of Risk Governance, Assurance, and Transfer." In *Managing Risk in Nanotechnology*, edited by Finbarr Murphy, Eamonn M. McAlea, and Martin Mullins, 137–44. Innovation, Technology, and Knowledge Management. Cham: Springer International Publishing. https://doi.org/10.1007/978-3-319-32392-3_8.

Merck, Ashton W., Khara D. Grieger, Maude Cuchiara, and Jennifer Kuzma. 2022. "What Role Does Regulation Play in Responsible Innovation of Nanotechnology in Food and Agriculture? Insights and Framings from U.S. Stakeholders." *Bulletin of Science, Technology & Society*, June, 027046762211020. https://doi.org/10.1177/02704676221102066.

Merck, Ashton W., Khara D. Grieger, and Jennifer Kuzma. 2022. "How Can We Promote the Responsible Innovation of Nano-Agrifood Research?" *Environmental Science & Policy* 137 (November):185–90. https://doi.org/10/gs7dmb.

Meyer, David E., and Venkata K. K. Upadhyayula. 2014. "The Use of Life Cycle Tools to Support Decision Making for Sustainable Nanotechnologies." *Clean Technologies and Environmental Policy* 16 (4): 757–72. https://doi.org/10/f5zqs7.

Miettinen, Mirella. 2021. "'By Design' and Risk Regulation: Insights from Nanotechnologies." *European Journal of Risk Regulation* 12 (4): 775–91. https://doi.org/10.1017/err.2020.58.
Milburn, Colin. 2010. *Nanovision: Engineering the Future*. Duke University Press. https://doi.org/10.1215/9780822391487.
Milford, Richard, and Jameson M. Wetmore. 2013. "A New Model for Public Engagement: The Dialogue on Nanotechnology and Religion." In *Nanotechnology, the Brain, and the Future*, edited by Sean A. Hays, Jason Scott Robert, Clark A. Miller, and Ira Bennett, 97–111. Dordrecht: Springer Netherlands. https://doi.org/10.1007/978-94-007-1787-9_6.
Miller, Georgia, and Gyorgy Scrinis. 2010. "The Role of NGOs in Governing Nanotechnologies: Challenging the 'benefits versus Risks' Framing of Nanotech Innovation." In *International Handbook on Regulating Nanotechnologies*, 409–45.
Miller, Georgia, and Fern Wickson. 2015. "Risk Analysis of Nanomaterials: Exposing Nanotechnology's Naked Emperor." *Review of Policy Research* 32 (4): 485–512. https://doi.org/10.1111/ropr.12129.
Mirabile, Marco, Fabio Boccuni, Diana Gagliardi, Bruna Maria Rondinone, and Sergio Iavicoli. 2014. "Workplace Exposure to Engineered Nanomaterials: The Italian Path for the Definition of Occupational Health and Safety Policies." *Health Policy* 117 (1): 128–34. https://doi.org/10/f2xsq7.
Mody, Cyrus C.M. 2010. "Institutions as Stepping-Stones: Rick Smalley and the Commercialization of Nanotubes." Studies in Materials Innovation. Philadelphia, US: Chemical Heritage Foundation.
Moore, Kelly. 2020. "Capitalisms, Generative Projects and the New STS." *Science as Culture*, December, 1–16. https://doi.org/10/ghpc8k.
Morose, Gregory. 2010. "The 5 Principles of 'Design for Safer Nanotechnology.'" *Journal of Cleaner Production* 18 (3): 285–89. https://doi.org/10/dhc9tn.
Mount, Matthew, Simon Milewski, and Kiran Fernandes. 2015. "Exploring the Knowledge Complexities of Innovation Intermediaries: The Case of Nanotechnology in the UK." *International Journal of Technology Management* 69 (1): 20. https://doi.org/10/f7ng6d.
Mumberg, Tabea, Steffen Foss Hansen, Anders Baun, and Rickard Arvidsson. 2023. "Assessment of Graphene-Based Materials against the Substances of Very High Concern Criteria." Scientific Report E2023:001. Division of Environmental Systems Analysis: Chalmers University of Technology, Department of Technology Management and Economics.
Munshi, Debashish, Priya A. Kurian, Talei Morrison, and Sandra L. Morrison. 2016. "Redesigning the Architecture of Policy-Making: Engaging with Māori on Nanotechnology in New Zealand." *Public Understanding of Science* 25 (3): 287–302. https://doi.org/10/g83bnn.
Nielsen, Maria Bille, Lars Skjolding, Anders Baun, and Steffen Foss Hansen. 2023. "European Nanomaterial Legislation in the Past 20 Years – Closing the Final Gaps." *NanoImpact* 32 (October):100487. https://doi.org/10/gtbsbw.
Nordmann, Alfred. 2007. "If and Then: A Critique of Speculative NanoEthics." *NanoEthics* 1 (1): 31–46. https://doi.org/10/c6n9pw.
OECD. 2020. "Moving Towards a Safe(r) Innovation Approach (SIA) for More Sustainable Nanomaterials and Nano-Enabled Products." 96. Series on the Safety of Manufactured Nanomaterials. Organisation for Economic Co-operation and Development. https://one.oecd.org/document/ENV/JM/MONO(2020)36/REV1/en/pdf.

——. 2023a. “Economic Instruments to Incentivise Substitution of Chemicals of Concern – a Review.” 79. OECD Series on Risk Management of Chemicals. OECD: Organisation for Economic Co-operation and Development. https://doi.org/10.1787/d73c0786-en.
——. 2023b. “Lessons Learned from Third-Party Approaches That Support Substitution of Chemicals of Concern.” No. 78. Series on Risk Management. OECD: Organisation for Economic Co-operation and Development. https://policycommons.net/artifacts/3812183/lessons-learned-from-third-party-approaches-that-support-substitution-of-chemicals-of-concern/4618099/.
Palmås, Karl, and Nicholas Surber. 2022. “Legitimation Crisis in Contemporary Technoscientific Capitalism.” *Journal of Cultural Economy* 15 (3): 373–79. https://doi.org/10/gp535d.
Palonen, Kari. 2003. “Four Times of Politics: Policy, Polity, Politicking, and Politicization.” *Alternatives: Global, Local, Political* 28 (2): 171–86. https://doi.org/10/gfsqq4.
Pellizzoni, Luigi. 2012. “Strong Will in a Messy World. Ethics and the Government of Technoscience.” *NanoEthics* 6 (3): 257–72. https://doi.org/10/gf658p.
Petersen, Alan, and Diana M. Bowman. 2012. “Engaging Whom and for What Ends? Australian Stakeholders’ Constructions of Public Engagement in Relation to Nanotechnologies.” *Ethics in Science and Environmental Politics* 12 (2): 67–79. https://doi.org/10/gg3w5j.
Pfersdorf, S.-P. 2012. “Governing Nanotechnology through Stakeholder Dialogues: The Example of the German NanoKommission.” *Australian Journal of Emerging Technologies and Society* 10 (1): 45–60.
Phuong, Phung Thuy, and Arthur P. J. Mol. 2004. “Communities as Informal Regulators: New Arrangements in Industrial Pollution Control in Viet Nam.” *Journal of Risk Research* 7 (4): 431–44. https://doi.org/10/dxrg24.
Piccinno, Fabiano, Fadri Gottschalk, Stefan Seeger, and Bernd Nowack. 2012. “Industrial Production Quantities and Uses of Ten Engineered Nanomaterials in Europe and the World.” *Journal of Nanoparticle Research* 14 (9): 1109. https://doi.org/10.1007/s11051-012-1109-9.
Pidgeon, Nick, and Tee Rogers-Hayden. 2007. “Opening up Nanotechnology Dialogue with the Publics: Risk Communication or ‘Upstream Engagement’?” *Health, Risk & Society* 9 (2): 191–210. https://doi.org/10/fgp2wf.
Poel, Ibo van de, and Zoë Robaey. 2017. “Safe-by-Design: From Safety to Responsibility.” *NanoEthics* 11 (3): 297–306. https://doi.org/10/ggqcrk.
Pollock, Neil, and Robin Williams. 2010. “The Business of Expectations: How Promissory Organizations Shape Technology and Innovation.” *Social Studies of Science* 40 (4): 525–48. https://doi.org/10/bmdbm8.
Porcari, Andrea, Elisabetta Borsella, Christina Benighaus, Khara Grieger, Panagiotis Isigonis, Somik Chakravarty, Pete Kines, and Keld Alstrup Jensen. 2019. “From Risk Perception to Risk Governance in Nanotechnology: A Multi-Stakeholder Study.” *Journal of Nanoparticle Research* 21 (11): 245. https://doi.org/10/gqwhmt.
Randles, Sally, Elise Tancoigne, and Pierre-Benoît Joly. 2022. “Two Tribes or More? The Historical Emergence of Discourse Coalitions of Responsible Research and Innovation (Rri) and Responsible Research and Innovation (RRI).” *Journal of Responsible Innovation*, June, 1–27. https://doi.org/10/grzxkn.
Reichow, Aline. 2017. “Co-Regulation of Nanomaterials: On Collaborative Business Association Activities Directed at Contributing to Occupational Health and Safety.” In *Embedding New Technologies into Society: A Regulatory, Ethical and Societal Perspective*, edited

by Diana M. Bowman, Elen Stokes, and Arie Rip, 1st ed. Jenny Stanford Publishing. https://doi.org/10.1201/9781315379593.
Reichow, Aline, and Bärbel Dorbeck-Jung. 2013. "Discovering Specific Conditions for Compliance with Soft Regulation Related to Work with Nanomaterials." *NanoEthics* 7 (1): 83–92. https://doi.org/10/g8z7f5.
Renn, O., and Mihail C. Roco. 2006. "Nanotechnology and the Need for Risk Governance." *Journal of Nanoparticle Research* 8 (2): 153–91. https://doi.org/10.1007/s11051-006-9092-7.
Rhodes, R. A. W. 1996. "The New Governance: Governing without Government." *Political Studies* 44 (4): 652–67. https://doi.org/10/bmqps3.
Rip, Arie. 2003. "Constructing Expertise: In a Third Wave of Science Studies?" *Social Studies of Science* 33 (3): 419–34. https://doi.org/10/crsqvb.
——. 2006. "Folk Theories of Nanotechnologists." *Science as Culture* 15 (4): 349–65. https://doi.org/10/bgvvxb.
——. 2020. *Nanotechnology and Its Governance*. London; New York: Routledge, Taylor & Francis Group.
Roco, Mihail C. 2011. "The Long View of Nanotechnology Development: The National Nanotechnology Initiative at 10 Years." *Journal of Nanoparticle Research* 13 (2): 427–45. https://doi.org/10/bv6vsm.
——. 2023. "National Nanotechnology Initiative at 20 Years: Enabling New Horizons." *Journal of Nanoparticle Research* 25 (10): 197. https://doi.org/10/gtndv9.
Rodríguez, Hannot. 2018. "Nanotechnology and Risk Governance in the European Union: The Constitution of Safety in Highly Promoted and Contested Innovation Areas." *NanoEthics* 12 (1): 5–26. https://doi.org/10/gc7ssj.
Rodríguez, Hannot, Erik Fisher, and Daan Schuurbiers. 2013. "Integrating Science and Society in European Framework Programmes: Trends in Project-Level Solicitations." *Research Policy* 42 (5): 1126–37. https://doi.org/10/g824bb.
Rogers-Hayden, T., and N. Pidgeon. 2006. "Reflecting upon the UK's Citizens' Jury on Nanotechnologies: NanoJury UK." *Nanotechnology Law and Business* 3 (2): 167–78.
Roig, Antoni. 2018. "Nanotechnology Governance: From Risk Regulation to Informal Platforms." *NanoEthics* 12 (2): 115–21. https://doi.org/10/gdwcdb.
Roubert, François, Marie-Gabrielle Beuzelin-Ollivier, Margarethe Hofmann-Amtenbrink, Heinrich Hofmann, and Alessandra Hool. 2016. "'Nanostandardization' in Action: Implementing Standardization Processes in a Multidisciplinary Nanoparticle-Based Research and Development Project." *NanoEthics* 10 (1): 41–62. https://doi.org/10/f8fh7h.
Royal Society and Royal Academy of Engineering. 2004. *Nanoscience and Nanotechnologies: Opportunities and Uncertainties*. London: The Royal Society : Royal Academy of Engineering.
Rubalcaba Medina, Analuisa, Steffen Foss Hansen, Fernando J. Rodriguez Macias, and Anders Baun. 2024. "A Design-Phase Environmental Safe-and-Sustainable-by-Design Categorization Tool for the Development and Innovation of Nano-Enabled Advanced Materials (AdMaCat)." *Environmental Science: Nano* 11 (9): 3761–73. https://doi.org/10/gzmvf4.
Saille, Stevienna de. 2022. "New Horizons, Old Friends: Taking an 'ARIA in Six Keys' Approach to the Future of R(R)I." *Journal of Responsible Innovation*, March, 1–5. https://doi.org/10/grzxkp.

Saldívar-Tanaka, Laura, and Steffen Foss Hansen. 2021. "Should the Precautionary Principle Be Implemented in Europe with Regard to Nanomaterials? Expert Interviews." *Journal of Nanoparticle Research* 23 (3): 70. https://doi.org/10/gjkkh2.

Sandler, Ronald, and W. D. Kay. 2006. "The GMO-Nanotech (Dis)Analogy?" *Bulletin of Science, Technology & Society* 26 (1): 57–62. https://doi.org/10/b3s4f9.

Schuijer, Jantien Willemijn, Jacqueline Broerse, and Frank Kupper. 2021. "Juggling Roles, Experiencing Dilemmas: The Challenges of SSH Scholars in Public Engagement." *NanoEthics* 15 (2): 169–89. https://doi.org/10/gmw48q.

Schwarz-Plaschg, Claudia, Angela Kallhoff, and Iris Eisenberger. 2017. "Making Nanomaterials Safer by Design?" *NanoEthics* 11 (3): 277–81. https://doi.org/10/g83543.

Seifert, Franz, and Camilo Fautz. 2021. "Hype After Hype: From Bio to Nano to AI." *NanoEthics* 15 (2): 143–48. https://doi.org/10/gmw48s.

Seifert, Franz, and Alexandra Plows. 2014. "From Anti-Biotech to Nano-Watch: Early Risers and Spin-Off Campaigners in Germany, the UK and Internationally." *NanoEthics* 8 (1): 73–89. https://doi.org/10/f6pd5f.

Selin, Cynthia. 2007. "Expectations and the Emergence of Nanotechnology." *Science, Technology, & Human Values* 32 (2): 196–220. https://doi.org/10/ck9qf6.

——. 2011. "Negotiating Plausibility: Intervening in the Future of Nanotechnology." *Science and Engineering Ethics* 17 (4): 723–37. https://doi.org/10/dx6gj4.

Selin, Cynthia, and Rebecca Hudson. 2010. "Envisioning Nanotechnology: New Media and Future-Oriented Stakeholder Dialogue." *Technology in Society* 32 (3): 173–82. https://doi.org/10/dmwd8s.

Sharkey, K., and L. Gillam. 2010. "Should Patients with Self-Inflicted Illness Receive Lower Priority in Access to Healthcare Resources? Mapping out the Debate." *Journal of Medical Ethics* 36 (11): 661–65. https://doi.org/10/dsxzp5.

Shelley-Egan, Clare. 2010. "The Ambivalence of Promising Technology." *NanoEthics* 4 (2): 183–89. https://doi.org/10/ds9647.

Shelley-Egan, Clare, and Diana M. Bowman. 2018. "Nanotechnologies: The Catalyst for Responsible Research and Innovation." In *Nanotechnology Environmental Health and Safety*, 33–55. Elsevier. https://doi.org/10.1016/B978-0-12-813588-4.00003-8.

Shelley-Egan, Clare, Diana M. Bowman, and Douglas K. R. Robinson. 2018. "Devices of Responsibility: Over a Decade of Responsible Research and Innovation Initiatives for Nanotechnologies." *Science and Engineering Ethics* 24 (6): 1719–46. https://doi.org/10/gfrc69.

Shelley-Egan, Clare, and Sarah R. Davies. 2013. "Nano-Industry Operationalizations of 'Responsibility': Charting Diversity in the Enactment of Responsibility." *Review of Policy Research* 30 (5): 588–604. https://doi.org/10/f5djzk.

Shew, Ashley. 2009. "Nanotechnology's Future: Considerations for the Professional." In *Nanotechnology & Society*, edited by Fritz Allhoff and Patrick Lin, 127–46. Dordrecht: Springer Netherlands. https://doi.org/10.1007/978-1-4020-6209-4_7.

Shin, Ki-Young. 2016. "Risk and the Emergence of New Subpolitics in Japan." In *Risk and Public Policy in East Asia*, edited by Raymond K. H. Chan, Mutsuko Takahashi, and Lillian Lih-rong Wang, 205–17. London and New York: Routledge. https://doi.org/10.4324/9781315606484-19.

Sinclair, Darren. 1997. "Self-Regulation Versus Command and Control? Beyond False Dichotomies." *Law & Policy* 19 (4): 529–59. https://doi.org/10/ff5mtg.

Soeteman-Hernandez, Lya G., Margarita D. Apostolova, Cindy Bekker, Susan Dekkers, Roland C. Grafström, Monique Groenewold, Yordan Handzhiyski, et al. 2019. "Safe

Innovation Approach: Towards an Agile System for Dealing with Innovations." *Materials Today Communications* 20 (September):100548. https://doi.org/10/gh8vkz.
Solla Price, Derek de. 1984. "The Science/Technology Relationship, the Craft of Experimental Science, and Policy for the Improvement of High Technology Innovation." *Research Policy* 13 (1): 3–20. https://doi.org/10/d6rbzz.
Sparrow, Robert. 2007. "Revolutionary and Familiar, Inevitable and Precarious: Rhetorical Contradictions in Enthusiasm for Nanotechnology." *NanoEthics* 1 (1): 57–68. https://doi.org/10.1007/s11569-007-0008-5.
Sreekumar, T.T., and Shobha Vadrevu. 2013. "Subpolitics and Democracy: The Role of New Media in the 2011 General Elections in Singapore." *Science, Technology and Society* 18 (2): 231–49. https://doi.org/10/g5xsj5.
Stevenson, Nick. 2012. "Localization as Subpolitics: The Transition Movement and Cultural Citizenship." *International Journal of Cultural Studies* 15 (1): 65–79. https://doi.org/10/c4b23k.
Stilgoe, Jack. 2007. *Nanodialogues: Experiments in Public Engagement with Science*. London: Demos.
Stirling, Andy. 2008. "'Opening Up' and 'Closing Down': Power, Participation, and Pluralism in the Social Appraisal of Technology." *Science, Technology, & Human Values* 33 (2): 262–94. https://doi.org/10/cfpsn5.
Stokes, E. 2013. "DEMAND FOR COMMAND: RESPONDING TO TECHNOLOGICAL RISKS AND SCIENTIFIC UNCERTAINTIES." *Medical Law Review* 21 (1): 11–38. https://doi.org/10/g8zcbc.
Suraud, Marie-Gabrielle. 2019. "From 'Safe by Design' to Scientific Changes: Unforeseen Effects of Controversy Surrounding Nanotechnology in France." *NanoEthics* 13 (2): 103–12. https://doi.org/10/ghpc74.
Svendsen, Claus, Lee A. Walker, Marianne Matzke, Elma Lahive, Samuel Harrison, Alison Crossley, Barry Park, et al. 2020. "Key Principles and Operational Practices for Improved Nanotechnology Environmental Exposure Assessment." *Nature Nanotechnology* 15 (9): 731–42. https://doi.org/10/gg95tj.
Swierstra, Tsjalling, and Arie Rip. 2007. "Nano-Ethics as NEST-Ethics: Patterns of Moral Argumentation About New and Emerging Science and Technology." *NanoEthics* 1 (1): 3–20. https://doi.org/10/bdw4df.
Taniguchi, Norio. 1974. "On the Basic Concept of Nano-Technology." In *Proceedings of the International Conference on Production Engineering*. Vol. Part II. Tokyo: The Japan Society of Precision Engineering and International Institution for Production Engineering Research.
Teo, Belicia, and Sulfikar Amir. 2021. "Contesting Relations of Definition: Climate Risk and Subpolitics in Singapore." *Environmental Sociology* 7 (3): 200–213. https://doi.org/10/gpg4tt.
Throne-Holst, Harald, and Eivind Stø. 2008. "Who Should Be Precautionary? Governance of Nanotechnology in the Risk Society." *Technology Analysis & Strategic Management* 20 (1): 99–112. https://doi.org/10/fgkmqv.
Tyfield, David. 2012. "A Cultural Political Economy of Research and Innovation in an Age of Crisis." *Minerva* 50 (2): 149–67. https://doi.org/10/f33vnn.
——, ed. 2017. *The Routledge Handbook of the Political Economy of Science*. Abingdon, Oxon ; New York, NY: Routledge.
Van Broekhuizen, Pieter, Fleur Van Broekhuizen, Ralf Cornelissen, and Lucas Reijnders. 2012. "Workplace Exposure to Nanoparticles and the Application of Provisional

Nanoreference Values in Times of Uncertain Risks." *Journal of Nanoparticle Research* 14 (4): 770. https://doi.org/10/f99vnz.
Vance, Marina E, Todd Kuiken, Eric P Vejerano, Sean P McGinnis, Michael F Hochella, David Rejeski, and Matthew S Hull. 2015. "Nanotechnology in the Real World: Redeveloping the Nanomaterial Consumer Products Inventory." *Beilstein Journal of Nanotechnology* 6 (August):1769–80. https://doi.org/10/brg2.
Vihma, Peeter. 2016. "Internet, Activism and Politics: The Repertoires and Rhetoric of Estonian Internet Activists." *Studies of Transition States and Societies* 8 (2): 64–80.
Walsh, Scott, John M. Balbus, Richard Denison, and Karen Florini. 2008. "Nanotechnology: Getting It Right the First Time." *Journal of Cleaner Production* 16 (8–9): 1018–20. https://doi.org/10/c3827x.
Wang, Xi. 2016. "Revisiting 'Upstream Public Engagement': From a Habermasian Perspective." *NanoEthics* 10 (1): 63–74. https://doi.org/10/f8fjr6.
Wehling, Peter. 2012. "From Invited to Uninvited Participation (and Back?): Rethinking Civil Society Engagement in Technology Assessment and Development." *Poiesis & Praxis* 9 (1–2): 43–60. https://doi.org/10/gp6rj2.
Wesdorp, Julia, and Erik Hans Klijn. 2024. "Supporter or Rival: Developing a Network Governance Approach About the Role of Surrogate Inspectorates in Regulatory Governance." *Perspectives on Public Management and Governance* 7 (3): 101–12. https://doi.org/10/g9f9rh.
Westlake, Martin. 2024. "Developing the Concept of *Consequential* Senior European Union Civil Servants as Sub-Political Policy Entrepreneurs." *European Politics and Society*, October, 1–22. https://doi.org/10/g8qn7f.
Whittington, Richard, and Basak Yakis-Douglas. 2020. "The Grand Challenge of Corporate Control: Opening Strategy to the Normative Pressures of Networked Professionals." *Organization Theory* 1 (4): 2631787720969697. https://doi.org/10/ghj6gh.
Wickson, Fern, and Ellen-Marie Forsberg. 2015. "Standardising Responsibility? The Significance of Interstitial Spaces." *Science and Engineering Ethics* 21 (5): 1159–80. https://doi.org/10/f7rmx5.
Widler, Tobias, Christoph Meili, Elena Semenzin, Vrishali Subramanian, Alex Zabeo, Danail Hristozov, and Antonio Marcomini. 2016. "Organisational Risk Management of Nanomaterials Using SUNDS: The Contribution of CENARIOS®." In *Managing Risk in Nanotechnology*, edited by Finbarr Murphy, Eamonn M. McAlea, and Martin Mullins, 219–35. Innovation, Technology, and Knowledge Management. Cham: Springer International Publishing. https://doi.org/10.1007/978-3-319-32392-3_12.
Wilsdon, James. 2004. "The Politics of Small Things: Nanotechnology, Risk, and Uncertainty." *IEEE Technology and Society Magazine* 23 (4): 16–21. https://doi.org/10/bsbdn6.
Wilsdon, James, and Rebecca Willis. 2004. *See-through Science: Why Public Engagement Needs to Move Upstream*. London: Demos.
Wood, Stephen, Alison Geldart, and Richard Jones. 2008. "Crystallizing the Nanotechnology Debate." *Technology Analysis & Strategic Management* 20 (1): 13–27. https://doi.org/10/d6sk7t.
Wright, Paul Fa. 2016. "Potential Risks and Benefits of Nanotechnology: Perceptions of Risk in Sunscreens." *Medical Journal of Australia* 204 (10): 369–70. https://doi.org/10/ggxg3b.
Wullweber, Joscha. 2008. "Nanotechnology– An Empty Signifier à Venir? A Delineation of a Techno-Socio-Economical Innovation Strategy." *Science, Technology & Innovation Studies*, July. https://doi.org/10/ggkk6n.

Wynne, Brian. 1992. “Misunderstood Misunderstanding: Social Identities and Public Uptake of Science.” *Public Understanding of Science* 1 (3): 281–304. https://doi.org/10/b5sswt.
——. 2001. “Creating Public Alienation: Expert Cultures of Risk and Ethics on GMOs.” *Science as Culture* 10 (4): 445–81. https://doi.org/10/dw8ht6.
——. 2003. “Seasick on the Third Wave? Subverting the Hegemony of Propositionalism: Response to Collins & Evans (2002).” *Social Studies of Science* 33 (3): 401–17. https://doi.org/10/ch9sch.
Åm, Heidrun. 2011a. “Regulating the Unknown: Governing Nanotechnologies By a Logic of Pre-Emption.” University of Vienna. https://utheses.univie.ac.at/detail/14564.
——. 2011b. “Trust as Glue in Nanotechnology Governance Networks.” *NanoEthics* 5 (1): 115–28. https://doi.org/10/bt2k9r.
——. 2013. “‘Don’t Make Nanotechnology Sexy, Ensure Its Benefits, and Be Neutral’: Studying the Logics of New Intermediary Institutions in Ambiguous Governance Contexts.” *Science and Public Policy* 40 (4): 466–78. https://doi.org/10/f47525.
——. 2019. “Limits of Decentered Governance in Science-Society Policies.” *Journal of Responsible Innovation* 6 (2): 163–78. https://doi.org/10/gj7sjq.

Wynne, Brian. 1992. “Misunderstood Misunderstanding: Social Identities and Public Uptake of Science.” *Public Understanding of Science* 1 (3): 281–304. https://doi.org/10/b5sswt.
——. 2001. “Creating Public Alienation: Expert Cultures of Risk and Ethics on GMOs.” *Science as Culture* 10 (4): 445–81. https://doi.org/10/dw8ht6.
——. 2003. “Seasick on the Third Wave? Subverting the Hegemony of Propositionalism: Response to Collins & Evans (2002).” *Social Studies of Science* 33 (3): 401–17. https://doi.org/10/ch9sch.
Åm, Heidrun. 2011a. “Regulating the Unknown: Governing Nanotechnologies By a Logic of Pre-Emption.” University of Vienna. https://utheses.univie.ac.at/detail/14564.
——. 2011b. “Trust as Glue in Nanotechnology Governance Networks.” *NanoEthics* 5 (1): 115–28. https://doi.org/10/bt2k9r.
——. 2013. “‘Don’t Make Nanotechnology Sexy, Ensure Its Benefits, and Be Neutral’: Studying the Logics of New Intermediary Institutions in Ambiguous Governance Contexts.” *Science and Public Policy* 40 (4): 466–78. https://doi.org/10/f47525.
——. 2019. “Limits of Decentered Governance in Science-Society Policies.” *Journal of Responsible Innovation* 6 (2): 163–78. https://doi.org/10/gj7sjq.