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Responsible Innovation for Wicked Societal Challenges
An Exploration of Strengths and Limitations

Wiarda, M.J.

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Responsible Innovation for Wicked Societal Challenges

An Exploration of Strengths and Limitations

Martijn Wiarda

Simon Stevin Series in the Ethics of Technology

Responsible Innovation for Wicked Societal Challenges

An Exploration of Strengths and Limitations

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An Exploration of Strengths and Limitations

Dissertation

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by

Martijn WIARDA

Master of Science in Innovation Sciences
Utrecht University, the Netherlands
born in Woerden, the Netherlands

This dissertation has been approved by the promotors.

Composition of the doctoral committee:

Rector Magnificus	chairperson
Prof.dr.mr.ir. N. Doorn	Delft University of Technology, promotor
Dr. G. van de Kaa	Delft University of Technology, promotor

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Dr. E. Yaghmaei contributed significantly to the development of the dissertation as a supervisor.

Wiarda, M.

Responsible Innovation for Wicked Societal Challenges: An Exploration of Strengths and Limitations

Department for Values, Technology and Innovation
Faculty of Technology, Policy and Management
Delft University of Technology
The Netherlands

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Chapter 3

Wiarda, M., van de Kaa, G., Yaghmaei, E., & Doorn, N., (unpublished manuscript) Wrestling with Wicked problems: Approaches from Responsible Innovation.

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Wiarda, M., van de Kaa, G., Doorn, N., & Yaghmaei, E., (2022) Responsible Innovation and De Jure Standardisation: An In-Depth Exploration of Moral Motives, Barriers, and Facilitators. *Science and Engineering Ethics* 28, 65. https://doi.org/10.1007/s11948-022-00415-z

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Wiarda, M., Coenen, T., & Doorn, N., (2023) Operationalizing Contested Problem-Solution Spaces: The Case of Dutch Circular Construction. *Environmental Innovation & Societal Transitions*, 48, 100752, https://doi.org/10.1016/j.eist.2023.100752

Chapter 7

Wiarda, M., & Doorn, N. (under review) Responsible Innovation and Societal Challenges: The Multi-Scalarity Dilemma.

All chapters of this dissertation are published or under review, with the exception of Chapter 3. All co-authors have granted permission to use their co-authored paper in this dissertation. These co-authors include Neelke Doorn (all chapters), Geerten van de Kaa (Chapter 2, 3, 4, and 5), Emad Yaghmaei (Chapter 2, 3, 4, and 5), Vladimir C.M. Sobota (Chapter 5), Matthijs J. Janssen (Chapter 5), and Tom B.J. Coenen (Chapter 6).

Summary

Responsible Innovation for Wicked Societal Challenges: An Exploration of Strengths and Limitations

Innovators are increasingly called upon to help resolve *wicked* societal challenges such as climate change, pandemics, and social injustice. The largely irreducible complexity, uncertainty, and contestation associated with these wicked problems require novel approaches that help navigate normative and epistemic considerations for decision-making. *Responsible Innovation* is a procedural approach that many scholars and practitioners believe could offer this.

I understand Responsible Innovation as an inclusive and risk-mitigating approach to innovation. It aims to align innovations with the values and worldviews of society through four widely agreed-upon procedural dimensions known as the AIRR dimensions: *anticipation*, *inclusion*, *reflexivity*, and *responsiveness*. Anticipation refers to considering probable, possible, and desirable impacts of innovation. Inclusion points to the early identification of the values and worldviews of diverse stakeholders. Reflexivity urges actors to reflect on how their values and practices align with those of stakeholders through forms of first and second-order reflection. Responsiveness means adequately reacting to anticipatory, inclusive, and reflexive insights to proactively shape or redirect innovations based on societal values and changing requirements. Early anticipatory and reflexive deliberations yield an understanding of what decisions and outcomes are deemed ethically acceptable in light of normative and epistemic uncertainty.

This dissertation advances our understanding of how to innovate responsibly in the context of wicked societal challenges by linking Responsible Innovation to the literature on wicked problems and studying their presumed relationship in an empirical setting. More specifically, it explores the usefulness of Responsible Innovation in tackling wicked problems by revealing various strengths and limitations of its approaches. The dissertation's main research question is: *To what extent can the procedural approach of Responsible Innovation, understood as the AIRR framework, be used to resolve wicked societal challenges?*

This dissertation is divided into five parts consisting of eight chapters, six of which were written and submitted as independent academic articles. The first part is the introductory chapter which presents the research questions and objectives (Chapter 1). The second part comprises of two systematic literature reviews exploring the

relationship between Responsible Innovation and Responsible Research and Innovation (Chapter 2) and wicked problems (Chapter 3). The third part is the empirical section that explores various strengths and limitations of some specific Responsible Innovation approaches identified in Chapter 3. These include *de jure* standardisation (Chapter 4), mission-oriented innovation policy (Chapter 5), and Q-methodology (Chapter 6). The fourth part (Chapter 7) diverges again by offering a discussion that invites future research on the scale of societal challenge-led forms of Responsible Innovation. Chapter 8 concludes by returning to the main research question and touches upon the main theoretical and practical implications of my work. It also outlines important limitations and highlights various promising avenues for future research.

Let us now turn to the content of the six core chapters. After the introduction, Chapter 2 identifies the shared research topics, knowledge bases, and shared organisation of Responsible Innovation with its cognate Responsible Research and Innovation to reveal a common ground for joint research. I use a co-word analysis, co-author analysis, and reference publication year spectroscopy to identify these, and subsequently describe how both notions matured into an increasingly cumulative and interconnected research trajectory despite their fragmented organization. I end this chapter by speculating that their commonalities may have caused some conflation of the two concepts.

In Chapter 3, I explore the potential methodological strengths and limitations of Responsible Innovation approaches in coping with the wickedness characteristics of societal challenges. I systematically identify approaches from the Responsible Innovation literature that exhibit the AIRR dimensions, after which I follow Vermaas & Pesch (2020) by evaluating these approaches *a priori* against ten methodological conditions based on the underlying dimensions of wicked problems. The analysis is thus an analytical reconstruction that offers an initial understanding of these approaches. The results suggest that several approaches appear useful in the context of wicked problems, and hint at various potential methodological strengths and drawbacks. Overcoming these drawbacks requires us to improve, combine, or reimagine approaches that have a greater shot at addressing challenges responsibly. This is particularly urgent for the organizational context which currently lacks a rich pool of capable approaches.

In Chapters 4, 5, and 6, I empirically explore the strengths and limitations of some specific approaches identified in Chapter 3. Chapter 4 focuses on *de jure* standardisation, and identifies factors that motivate, obstruct, and facilitate the AIRR dimensions of this process. My results suggest that many practitioners deem the AIRR dimensions important for establishing socially desirable standards. However, they also hint that the process is insufficiently able to develop such standards as practitioners perceive the process as inadequately inclusive and anticipatory. My results moreover indicate that the helpfulness of such consensus-based approaches for addressing societal challenges is limited due to their inability to deal with contestation.

Chapter 5 focuses on mission-oriented innovation policy as an approach to mobilise stakeholders behind shared goals to address societal challenges. I examine the effect of mission orientations on the public participatory performance of innovation projects. Using project-level data, I compute the statistical effect of (non-)mission orientations on the timing, openness, and (financial) influence of public participation in 1261 projects. I find that the specific mission theme is important for the participatory performance. My results suggest that mission-oriented projects correspond with earlier participation of more public actors. However, I find little evidence that they also consistently coincide with increased diversity and financial influence of public participants.

The last approach that I study is Q-methodology (Chapter 6). I examine how Q-methodology informs us about divergent sociotechnical imaginaries of wicked problems and potential solutions. I use the Dutch circular construction sector as my case study, and draw data from semi-structured interviews, policy documents, and a survey. I identify, describe, and compare three different imaginaries in terms of their problem-oriented and solution-oriented visions. These insights inform me about disagreements and common ground, and could help policymakers coevolve problem-solution framings. However, this approach does not necessarily provide insights into why disagreement emerges and whether this disagreement can be resolved. Q-methodology also does not inform us about the ubiquity of the identified imaginaries. I therefore find that Q-methodology has limitations that need to be compensated for.

Chapter 7 tackles a more holistic and conceptual inquiry. I claim that if Responsible Innovation approaches are to be deployed for wicked societal challenges, innovators cannot ignore the multi-scalarity of the wicked problems they intend to address. Multi-scalarity refers to the idea that wicked problems exist, unfold, and interact at multiple scales. It prompts the question of how Responsible Innovation should deal with the multi-scalarity of societal challenges. Many scholars exclusively focus on one particular scale, commonly either through a local or global approach, without explaining this choice. I explore rationales for both these two prevalent but largely opposing options, and suggest that local approaches are usually more grounded in contextual values and worldviews, whereas global approaches enjoy more collective and systemic responses. Addressing societal challenges requires innovators to ground resolutions in local values and worldviews and fit these into global efforts. I advocate a hybrid approach and suggest how Responsible Innovation could cope with the contradicting considerations associated with multi-scalarity. Innovators could combine complementary approaches, leverage so-called boundary objects, and embrace conflict.

With this dissertation, I wish to contribute to the discourse on Responsible Innovation in the context of wicked societal challenges, and to help understand some of its strengths and limitations in tackling these. I hope my work demonstrates how the notion of Responsible Innovation fosters collaborations but simultaneously reveals contestation. I argue that in order to tackle challenges, innovators may need to leverage boundary objects and combine complementary approaches to deal with (multi-scalar) conflict. I see potential in drawing inspiration from Responsible Innovation to foster responsible sociotechnical change that transforms systems in accordance with societal values and worldviews.

Samenvatting

Maatschappelijk Verantwoord Innoveren voor Wicked Problems: Een Verkenning van Sterktes en Beperkingen

Steeds vaker wordt er een beroep gedaan op innovatieve actoren om bij te dragen aan oplossingen voor zogenoemde *wicked problems*[1] zoals klimaatverandering, pandemieën en sociale onrechtvaardigheid. De grotendeels onreduceerbare complexiteit, onzekerheid, en onenigheid die gepaard gaan met deze hardnekkige problemen vragen om nieuwe benaderingswijzen die helpen normatieve en epistemische overwegingen voor besluitvorming in goede banen te leiden. *Maatschappelijk Verantwoord Innoveren* (Engels: Responsible Innovation) is een procedurele benadering die dit volgens veel wetenschappers en ervaringsdeskundigen zou kunnen bieden.

Ik beschouw Maatschappelijk Verantwoord Innoveren als een inclusieve en risicobeperkende benadering voor innovatie. Maatschappelijk Verantwoord Innoveren beoogt innovaties af te stemmen op waarden en wereldbeelden van de samenleving door middel van vier, breed geaccepteerde, procedurele dimensies die bekend staan als de AIRR-dimensies: *anticipatie*, *inclusie*, *reflexiviteit*, en *responsiviteit*. Anticipatie verwijst naar het vermogen om waarschijnlijke, mogelijke en wenselijke gevolgen van innovatie te verkennen. Inclusie duidt op de vroegtijdige identificatie van waarden en wereldbeelden van diverse belanghebbenden. Reflexiviteit moedigt actoren aan om na te denken over hoe hun waarden en wereldbeelden zich verhouden tot die van een bredere groep belanghebbenden door middel van eerste- en tweede-orde reflectie. Responsiviteit betekent het adequaat reageren op anticiperende, inclusieve en reflexieve inzichten om innovaties proactief vorm te geven en/of bij te sturen op basis van maatschappelijke waarden en veranderende behoeften. Als zodanig geven vroegtijdige anticiperende en reflexieve beraadslagingen inzicht in welke beslissingen en uitkomsten ethisch aanvaardbaar worden geacht in het licht van normatieve en epistemische onzekerheid.

Dit proefschrift vergroot het inzicht in hoe actoren verantwoord kunnen innoveren in de context van maatschappelijke uitdagingen. Dit inzicht wordt geleverd door het concept Maatschappelijk Verantwoord Innoveren te koppelen aan dat van wicked problems, en door hun veronderstelde relatie te bestuderen in een empirische setting. Mijn onderzoek legt in het bijzonder sterktes en beperkingen van

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[1] Bij gebrek aan een gangbare Nederlandse term gebruik ik de originele Engelse term 'wicked problems'.

Maatschappelijk Verantwoord Innoveren bloot bij het aanpakken van deze wicked problems. De hoofdvraag van dit proefschrift luidt: *In hoeverre kan de procedurele benadering van Maatschappelijk Verantwoord Innoveren, bij wijze van het AIRR-raamwerk, worden gebruikt om wicked problems te verhelpen?*

Dit proefschrift kan grofweg worden verdeeld in vijf delen die gezamenlijk bestaan uit acht hoofdstukken, waarvan er zes zijn geschreven en ingediend als zelfstandige wetenschappelijke artikelen. Het eerste deel betreft een inleidend hoofdstuk waarin ik de onderzoeksvragen en doelstellingen van het proefschrift presenteer (Hoofdstuk 1). Het tweede deel bestaat uit twee systematische literatuuronderzoeken die de relatie verkennen tussen Maatschappelijk Verantwoord Innoveren en Maatschappelijk Verantwoord Onderzoeken en Innoveren (Hoofdstuk 2; Engels: Responsible Research and Innovation), en de relatie verkennen tussen Maatschappelijk Verantwoord Innoveren en wicked problems (Hoofdstuk 3). Het derde deel is het empirische gedeelte van dit proefschrift dat verschillende sterktes en beperkingen onderzoekt van enkele specifieke benaderingen voor Maatschappelijk Verantwoord Innoveren die zijn geïdentificeerd in Hoofdstuk 3. Deze benaderingen betreffen *de jure* standaardisatie (Hoofdstuk 4), missiegedreven innovatiebeleid (Hoofdstuk 5), en Q-methodologie (Hoofdstuk 6). Het vierde deel van dit proefschrift (Hoofdstuk 7) divergeert conceptueel door een betoog te voeren dat toekomstig onderzoek uitnodigt naar de schaal van uitdagingsgeleide vormen van Maatschappelijk Verantwoord Innoveren. Tenslotte sluit het vijfde deel van dit proefschrift (Hoofdstuk 8) af met een terugkeer naar de hoofdvraag, en door in te gaan op de belangrijkste theoretische en praktische implicaties van mijn werk. Ook worden hier belangrijke beperkingen van mijn onderzoek benadrukt, en belicht ik enkele veelbelovende richtingen voor toekomstig onderzoek.

Laten we nu ingaan op de inhoud van de zes kernhoofdstukken. Na de inleiding identificeert Hoofdstuk 2 de gedeelde onderzoeksthema's, kennisgrondslagen en gedeelde organisatie van Maatschappelijk Verantwoord Innoveren en haar cognaat Maatschappelijk Verantwoord Onderzoeken en Innoveren als een gemeenschappelijke basis voor gezamenlijk onderzoek. Ik maak daarbij gebruik van een co-woord- en co-auteursanalyse, en een referentie publicatiejaar spectroscopie. Vervolgens beschrijf ik hoe beide stromingen zich in toenemende mate hebben ontwikkeld tot een cumulatief en onderling verbonden onderzoekstraject desondanks hun gefragmenteerde organisatie. Ik eindig dit hoofdstuk met de speculatie dat de onderlinge overeenkomsten van beide stromingen wellicht tot enige verwarring heeft geleid over de precieze inhoud van beide concepten.

In Hoofdstuk 3 verken ik potentiële methodologische sterktes en beperkingen van Maatschappelijk Verantwoord Innoveren in het omgaan met de kenmerken van wicked problems. Op een systematische wijze identificeer ik benaderingen uit de Maatschappelijk Verantwoord Innoveren literatuur die de AIRR-dimensies uitdragen. Daarna volg ik de onderzoeksmethode van Vermaas & Pesch (2020) door deze benaderingen *a priori* te evalueren op grond van tien methodologische voorwaarden die zijn gebaseerd op de onderliggende dimensies van wicked problems. Mijn analyse behelst dus een analytische reconstructie die leidt tot een ruw inzicht in deze benaderingen. De resultaten duiden erop dat verschillende benaderingen nuttig lijken in de context van wicked problems, en wijzen verder op verschillende potentiële methodologische sterktes en beperkingen. Het verhelpen van deze beperkingen vereist dat we benaderingen verbeteren, combineren of bedenken die geschikter zijn om uitdagingen op een verantwoorde wijze aan te pakken. Dit lijkt in het bijzonder dringend voor de organisatorische context, waar een rijke verscheidenheid aan bekwame benaderingen ontbreekt.

In de hoofdstukken 4, 5, en 6 onderzoek ik empirisch de sterktes en beperkingen van enkele specifieke benaderingen die in Hoofdstuk 3 zijn geïdentificeerd. Hoofdstuk 4 richt zich op *de jure* standaardisatie en identificeert factoren die de AIRR-dimensies van dit proces motiveren, belemmeren en bevorderen. Mijn resultaten duiden erop dat veel mensen uit de praktijk het proces als onvoldoende inclusief en anticiperend ervaren. Mijn resultaten wijzen bovendien erop dat de bruikbaarheid van dergelijke consensus-gedreven benaderingen gelimiteerd is in de context van maatschappelijke uitdagingen omdat ze slecht om kunnen gaan met onenigheid.

Hoofdstuk 5 focust op missiegedreven innovatiebeleid als benaderingswijze om belanghebbenden te mobiliseren achter gezamenlijke doelen die gericht zijn op het adresseren van maatschappelijke uitdagingen. Ik onderzoek het effect van missie-oriëntaties op het publieke participatievermogen van innovatieprojecten. Met behulp van projectgegevens bereken ik het statistisch effect van (niet-)missie-oriëntaties op het tijdstip, de openheid en (financiële) invloed van publieke participatie in 1261 projecten. Ik constateer dat het specifieke missiethema bepalend is voor het participatievermogen. Mijn resultaten suggereren dat missiegedreven projecten inderdaad corresponderen met eerdere participatie van meer publieke actoren, maar ik vind weinig bewijs dat ze ook consistent overeenkomen met een grotere diversiteit en financiële invloed van publieke participanten.

De laatste benadering die ik bestudeer is Q-methodologie (Hoofdstuk 6). Ik onderzoek hoe Q-methodologie ons informeert over uiteenlopende socio-technische denkbeelden over wicked problems en mogelijke resoluties. Ik gebruik de Nederlandse circulaire bouwsector als mijn casestudy en ontleen data aan semigestructureerd interviews, beleidsdocumenten en een enquête. Ik identificeer, beschrijf en vergelijk de verschillende denkbeelden in termen van hun probleemgerichte en oplossingsgerichte visies. Deze inzichten informeren over meningsverschillen en raakvlakken, en zouden beleidsmedewerkers kunnen helpen bij het co-evolueren van probleem- en oplossingsrichtingen. Deze benadering biedt echter niet per se inzicht in waarom onenigheid ontstaat en of dit conflict verholpen kan worden. Q-methodologie biedt evenmin informatie over de generaliseerbaarheid van de geïdentificeerde denkbeelden. Daarom constateer ik dat Q-methodologie beperkingen heeft die moeten worden gecompenseerd.

Hoofdstuk 7 behandelt een meer holistisch en conceptueel vraagstuk. Ik stel dat als benaderingen van Maatschappelijk Verantwoord Innoveren moeten worden ingezet voor wicked problems, dat innovatieve actoren de multi-scalariteit van de desbetreffende problemen niet kunnen negeren. Multi-scalariteit verwijst naar het fenomeen dat problemen zich op meerdere schalen manifesteren, ontwikkelen, en op elkaar inwerken. Dit roept de vraag op hoe Maatschappelijk Verantwoord Innoveren hier mee moet omgaan. Ik bespreek dat veel onderzoekers zich uitsluitend richten op één bepaalde schaal, meestal middels een lokale of mondiale benadering, zonder deze keuze te verantwoorden. Ik beschouw argumenten voor deze twee gangbare, maar grotendeels tegenstrijdige opties, en suggereer dat lokale benaderingen doorgaans beter geworteld zijn in contextuele waarden en wereldbeelden, terwijl mondiale benaderingen meer collectieve en systemische veranderingen uitlokken. Het aanpakken van maatschappelijke uitdagingen vereist inderdaad dat innovatieve actoren resoluties afstemmen op lokale waarden en wereldbeelden en deze tegelijkertijd positioneren in mondiale inspanningen. Ik pleit voor een hybride benadering en suggereer hoe Maatschappelijk Verantwoord Innoveren kan omgaan met multi-scalariteit: innovatieve actoren kunnen complementaire benaderingen combineren, zogenoemde *boundary objects*[2] benutten en conflicten omarmen.

Met dit proefschrift hoop ik bij te dragen aan de discussie omtrent Maatschappelijk Verantwoord Innoveren in de context van wicked problems, en meer inzicht te bieden in een aantal sterktes en limieten in de aanpak van deze uitdagingen. Ik hoop dat mijn werk laat zien hoe het idee van Maatschappelijk Verantwoord Innoveren samenwerking bevordert, maar tegelijkertijd ook onenigheid binnen die

[2] Bij gebrek aan een gangbare Nederlandse term gebruik ik de originele Engelse term 'boundary objects'.

samenwerking aan het licht brengt. Ik betoog dat innovatieve actoren wellicht gebruik moeten maken van boundary objects en complementaire benaderingen om (multi-scalaire) conflicten van uitdagingen aan te wenden. Ik zie potentieel in het ontlenen van inspiratie aan Maatschappelijk Verantwoord Innoveren om zodoende verantwoorde socio-technische veranderingen te bevorderen die overeenkomen met maatschappelijke waarden en wereldbeelden.

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1. Introduction

In the wake of the 21st century, scientists and innovators are increasingly called upon to help resolve pressing societal challenges. Climate change is perhaps one of the most notorious ones (Schot and Steinmueller, 2018). Not only do conflicts emerge regarding the normative and epistemic character of these challenges, but the required resolutions also incite social upheaval. By way of illustration, let us look at the discussion about geoengineering. Proposals to mitigate, avert, or even reverse climate change by forms of carbon dioxide removal or solar radiation reflection have led to heated debates regarding the social desirability of such so-called geoengineering methods (Pidgeon et al., 2013).

Despite the seemingly futuristic nature of geoengineering, various records have already reported several geoengineering cases across the globe. Although many of these cases are grounded in science, the imaginaries fuelling geoengineering share similarities with widespread forms of science-fiction and are often highly controversial (Jasanoff and Kim, 2015). Opponents of geoengineering argue that the epistemic and normative confidence in these technologies is naïve and advocate an immediate non-use agreement for (solar) geoengineering (Biermann et al., 2022). Critics express concerns related to the ramifying risks and uncertainties vis-a-vis global climates and ecosystems (The Royal Society, 2009). Geoengineering is additionally claimed to disregard or even discourage measures targeted at the underlying problems of climate change such as greenhouse gas emissions (Daniel and Andy, 2021). In contrast, proponents have argued that geoengineering should not be considered a solution to climate change but rather a last resort that helps us cope with disastrous consequences if we fail to address the root causes of climate change (Vaughan and Lenton, 2011). Several supporters subsequently plead to keep geoengineering open as an option (de Vries et al., 2022).

Although this dissertation does not focus on geoengineering, the controversy surrounding this potential response to climate change exemplifies how challenge-led resolutions in a broader sense represent urgent but contested matters that call for both scientific and ethical decision-making. Similar conflict dynamics can be found in the context of other challenges such as the COVID-19 pandemic, the Dutch nitrogen crisis, and the energy transition. Here, actors have radically different ideas about the problems and the required resolutions (Wanzenböck et al., 2020). Making the 'right' evidence-based decisions for the development of innovations in these contexts is therefore not straight forward and may even seem impossible.

This dissertation contributes to our understanding of how to innovate responsibly in such challenge-led environments. More specifically, it reveals some of the strengths and limitations of approaches to innovate responsibly. In the following sections of this chapter, I first introduce some of the theoretical concepts that lay at the heart of my contribution and then delineate my research approach and describe the structure of this dissertation.

1.1. Wicked Societal Challenges

Highly controversial societal challenges, like climate change, are frequently named *wicked problems* because of their vicious, tricky and aggressive nature (Rittel and Webber, 1973). Wicked problems are associated with complexity, uncertainty, and contestation (Farrell and Hooker, 2013). The complexity stems from their multi-scalar, multi-dimensional, multi-actor, and ever-changing character; the epistemic and normative uncertainty of wicked problems and their possible resolutions persistently impose a knowledge deficit on innovators (Hoffmann-Riem and Wynne, 2002; Wanzenböck et al., 2020); and the contestation that gives rise to heated debates partly emerges from the plurality of stakeholders with fundamentally different values and worldviews (Pesch and Vermaas, 2020; Schon and Rein, 1994).

Some scholars argue that the largely irreducible character of complexity, uncertainty, and contestation obstructs decision-makers from solving them at all (Head and Xiang, 2016; Xiang, 2013). Instead, they speak of 'resolving', 'addressing' or 'coping with' wickedness to unfold "a never ending discourse with reality, to discover yet more facets, more dimensions of action, more opportunities for improvement" (Dery, 1984, pp. 6–7). Such a provisional perspective requires innovators to shift from a sole outcome-oriented focus, to a procedural-oriented one (Daviter, 2017; Head, 2008).

1.2. Responsible Innovation

A procedural approach that many scholars and practitioners believe could help address societal challenges is *Responsible Innovation*, sometimes referred to as

Responsible Research and Innovation[3] (e.g., Genus and Stirling, 2018; Jakobsen et al., 2019; Owen et al., 2020; Von Schomberg, 2013). Although there are various understandings of Responsible Innovation, there are two approaches in particular that are widely adopted. Many scholars view Responsible Innovation as "a transparent, interactive process by which societal actors and innovators become mutually responsive to each other with a view to the (ethical) acceptability, sustainability and societal desirability of the innovation process and its marketable products (in order to allow a proper embedding of scientific and technological advances in our society)"(Von Schomberg, 2011, p. 9). Other scholars consider Responsible Innovation as "taking care of the future through collective stewardship of science and innovation in the present" (Stilgoe et al., 2013, p. 1570).

Given these two perspectives, I understand Responsible Innovation as an inclusive and risk-mitigating approach that facilitates a forward-looking form of responsibility. It builds on the view that innovations are not value-neutral, but rather inscribe a "vision of (or prediction about) the world" (Akrich, 1992, p. 208) and impose 'situated' values and worldviews on society (Haraway, 1988; Winner, 1980). It presumes that innovations are associated with various risks and uncertainties (Hoffmann-Riem and Wynne, 2002). Responsible Innovation has largely emerged from the fields of Ethics of Technology and Science & Technology Studies and has benefitted from extensive support from the European Commission through its 'Science with and for Society' H2020 programme (Owen and Pansera, 2019).

Although several studies in the field of Responsible Innovation are concerned with the purpose and outcomes of innovation, most studies have focused on the 'upstream' or 'midstream' *process* of innovation (e.g., Capurro et al., 2015; Fisher and Mahajan, 2006; Flipse et al., 2014; Rogers-Hayden and Pidgeon, 2007; Schuurbiers, 2011). A prevalent rationale for such a procedural approach is that early reflexive and anticipatory deliberations yield an understanding of what decisions and outcomes are deemed ethically acceptable in light of epistemic and normative uncertainty. Responsible Innovation aims to align innovations with the values and worldviews of society through four widely agreed upon procedural dimensions, i.e., *anticipation*, *inclusion*, *reflexivity*, and *responsiveness* (Stilgoe et al., 2013). In the following section, I will discuss these so-called AIRR dimensions in more detail.

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[3] Although there is a conceptual difference between Responsible Innovation and Responsible Research and Innovation, both terms are frequently used interchangeably. In this chapter, we use the term Responsible Innovation to refer to both concepts by reason of simplicity. In chapter 2 we will dissect the conceptual differences in-depth.

1.3. The AIRR Dimensions

Anticipation refers to the ability to consider the probable, possible, and desirable consequences of innovation (Börjesona et al., 2006) and prompts the question 'what if…?' (Ravetz, 1997). Because innovations inherently induce unexpected consequences, actors are urged to move beyond conventional risk management by considering uncertainties and unknowns (Hoffmann-Riem and Wynne, 2002; Stirling, 2010). More fundamentally it requires us to collectively articulate the 'right' impacts (Von Schomberg, 2014), taking into account both 'hard' and 'soft' impacts (van der Burg, 2009). Common visions of desirable sociotechnical futures may involve views on priorities for innovations, investments, power, and political dissent (Jasanoff and Kim, 2015, 2009). Exemplary approaches that may help define these visions are technology assessment (Kiran et al., 2015; Rip and van Lente, 2013), scenarios (Betten et al., 2018), and the Delphi method (Brier et al., 2020).

Inclusion points to the early identification of values, needs, and perspectives of diverse stakeholders (Stilgoe et al., 2013). There are various instrumental, substantive, and normative rationales for inclusion (Stirling, 2008). Perhaps the most prevalent argument is that it allows actors to reveal insights that cannot be determined *a priori* (Bauer et al., 2021). Inclusion may take forms of communication, consultation, and participation (Rowe and Frewer, 2005). In these processes, stakeholders will unlikely replace conventional innovators, but rather complement and ground them firmer into the real world (Harremoës et al., 2001). Inclusive approaches are frequently referred to as hybrid forums (Callon et al., 2009) such as focus groups, citizen panels, and consensus conferences (Rowe and Frewer, 2000).

Reflexivity urges actors to reflect on how their activities align with their social responsibilities through forms of first and second-order reflexivity. First-order reflexivity refers to the "consideration of problem definitions and evaluation of solutions" (Grin and Van De Graaf, 1996, p. 299) that are the extension of one's value system (Van de Poel and Zwart, 2010). While second-order reflexivity encourages actors to learn about this value system, these values are unchallenged in first-order reflexivity (Schuurbiers, 2011). Reflexivity inherently requires time (Steen, 2021) but becomes easier by including actors with different values and worldviews (Blok, 2014; Doorn et al., 2013). Standards, codes of conduct, and moratoriums are some tools that may contribute to one's reflexive capacity (Stilgoe et al., 2013).

Responsiveness means adequately reacting to anticipatory, inclusive, and reflexive insights to proactively shape or redirect innovations based on societal values and changing requirements (Stilgoe et al., 2013). Responses may be proactive or reactive

(Pellizzoni, 2004) but agency tends to be easier early on before path-dependencies have materialized (Collingridge, 1980; Genus and Stirling, 2018). Consensus is generally considered beneficial for a collective response. Yet, responsiveness does not assume consensus, but necessitates learning from conflict and diversity (Schot and Steinmueller, 2018). This is especially the case in the context of wicked problems that are inherently characterised by contestation (Rittel and Webber, 1973). Exemplary instruments that may facilitate responsiveness are challenge-led policies (Mazzucato, 2018a), standardisation (Wickson and Forsberg, 2015), and value-sensitive design (Friedman, 1996).

1.4. Research Approach: Problem and Objective

The topic of this dissertation's research is: Responsible Innovation for wicked societal challenges. Responsible Innovation is claimed to be a potentially useful approach to resolving societal challenges (e.g., Genus and Stirling, 2018; Jakobsen et al., 2019; Owen et al., 2020; Von Schomberg, 2013), which suggests that it should be able to deal with the difficulties associated with wicked problems. Yet, in developing approaches to Responsible Innovation that articulate the AIRR dimensions, scholars have not explicitly linked the concepts of wicked problems with Responsible Innovation. By linking Responsible Innovation to the external literature of wicked problems, and by studying the presumed relation between Responsible Innovation and wicked problems in an empirical setting, I will contribute to a better understanding of the conceptual links between Responsible Innovation and societal challenges.

I adopt the procedural definition of Stilgoe et al. (2013) for Responsible Innovation and draw from the AIRR framework as discussed above. I specifically examine how Responsible Innovation relates to wicked problems because this type of societal challenge allows me to study Responsible Innovation under some of the hardest conditions. The objective is to identify and explore various strengths and limitations of Responsible Innovation in addressing wicked societal challenges. The insights from this dissertation could help select and/or further develop approaches for a challenge-led form of Responsible Innovation. By extension, practitioners may more successfully address societal challenges.

1.5. Research Questions

The research question that corresponds with the aforementioned objective is: to what extent can the procedural approach of Responsible Innovation, understood as the AIRR framework, be used to resolve wicked societal challenges? This question should not be read in a strictly quantitative way. It is (non-exhaustively) answered through a series of conceptual and empirical studies that start from the concept of Responsible Innovation.

Because scholars hold very different understandings of what Responsible Innovation entails, Responsible Innovation studies have pursued different research topics and drawn on distinct knowledge bases. What is more, the terms Responsible Innovation and Responsible Research and Innovation have frequently been used as synonyms while some scholars argue that they are conceptually different (Owen and Pansera, 2019). I therefore first examine their commonalities (and differences) to lay a conceptual foundation on which this dissertation builds. The first sub-question is:

> (Q1) What are the shared research topics, knowledge bases, and shared organisation of Responsible Innovation and Responsible Research and Innovation as a common ground for joint research?

In order to answer this question, we draw on a combination of scientometric methods to identify shared topics (co-word analysis), knowledge bases (reference analysis), and the shared organisation (co-author analysis). The analyses suggests that the AIRR framework has been the most influential framework for Responsible Innovation in the last decade. Yet, there is no single dominant approach that articulates these four dimensions.

The next step is to take stock of Responsible Innovation approaches, and explore to what extent these are able to cope with the wickedness characteristics of societal challenges. The second sub-question therefore is:

> (Q2) What are the potential methodological strengths and weaknesses of Responsible Innovation approaches in coping with the wickedness characteristics of societal challenges?

In order to answer this question, we systematically review what approaches are used in the field of Responsible Innovation to articulate the AIRR dimensions, and explore how these approaches potentially deal with wickedness characteristics.

To further identify and explore various strengths and limitations of Responsible Innovation in addressing societal challenges, we proceed in an *a posteriori* fashion to answer Q3 to Q5. We non-exhaustively select (and occasionally combine) a number of Responsible Innovation approaches that we identified by answering Q2, and which we empirically study in what follows. These Responsible Innovation approaches do not per definition articulate *all* four dimensions, but may rather emphasize a selection of dimensions. As I will discuss, the broad nature of these approaches requires us to gather empirical data from a diverse set of cases and/or datasets. In addition, the studies that answer Q3-Q5 do not aim to comprehensively identify *all* limitations of Responsible Innovation. Instead, they allow us to yield more in-depth insights of which some may be generalized to a broader context.

First, we scrutinize *de jure* standardisation as an approach to Responsible Innovation. Many actors consider *de jure* standardisation as an inherently inclusive approach to inserting ethics in innovation processes. To better understand how Responsible Innovation is institutionalized in *de jure* standardization, and to identify what factors may influence this form of responsibility, I ask:

(Q3) What factors motivate, obstruct, and facilitate the AIRR dimensions of Responsible Innovation in *de jure* standardisation?

We research the *de jure* standardization processes of the Royal Dutch Normalisation Institute (NEN) by using in-depth interviews with managers, and subsequently distributing a comprehensive survey among its practitioners. Although we do not directly link this approach to wicked problems, our study does provide anecdotal evidence and other insights that help us answer the main research question of this dissertation.

Second, we study mission-oriented innovation policy as an increasingly popular approach for policymakers. Missions are considered potentially useful boundary objects that mobilize a broad set of stakeholders into a uniform direction. However, no research has yet explored how and if missions incentivize innovation processes to include public actors. I therefore prompt the sub-question:

(Q4) What is the effect of mission orientations on the public participatory performance of innovation projects?

To answer this question, we compute the effect of a (non-)mission orientation on the public participatory performance of 1261 innovation projects by analysing data provided by the Netherlands Enterprise Agency (RVO).

Third, we consider Q-methodology as an approach to identify and describe conflicting imaginaries on wicked problems and potential solutions. More specifically, we explore how such an approach may help resolve future-oriented contestation. I therefore ask:

> (Q5) How does Q-methodology inform us about divergent imaginaries on wicked problems and required solutions?

Q5 is answered by means of a Q-study that draws data from semi-structured interviews, policy documents, and a survey. These have been acquired from, or conducted with, actors from the Dutch circular construction sector to understand how conflicting visions can be navigated.

Taking an *a priori* lens, I have included an additional sub-question in response to insights that emerged from answering Q2. I find that Responsible Innovation does not explicitly consider the multi-scalarity of societal challenges when carrying out the AIRR dimensions, and that it (implicitly) tends to focus on exclusively a local or global scale. Multi-scalarity refers to the idea that wicked problems exist, unfold, and interact at multiple scales, and that 'grand' challenges are not contained but nearly always surpass geographical borders. I therefore raise the following sub-question:

> (Q6) How should Responsible Innovation deal with the multi-scalarity of societal challenges?

We discuss rationales for these two common but opposing approaches, and provide tentative insights into how multi-scalarity could be dealt with by uniting scales through a hybrid approach.

The dissertation is outlined as follows. After this introduction, Chapters 2 to 7 focus on answering the six sub-questions (Figure 1-1). Chapters 2 and 3 are both systematic literature reviews that lay a broad foundation after which Chapters 4 to 6 converge by focusing on particular approaches. Chapter 7 diverges by offering a discussion that invites future research on the scale of challenge-led forms of Responsible Innovation. Chapter 8 concludes by returning to the main research question. Here we subsequently discuss theoretical and practical implications, and several important limitations and avenues for future research for Responsible Innovation directed at societal challenges.

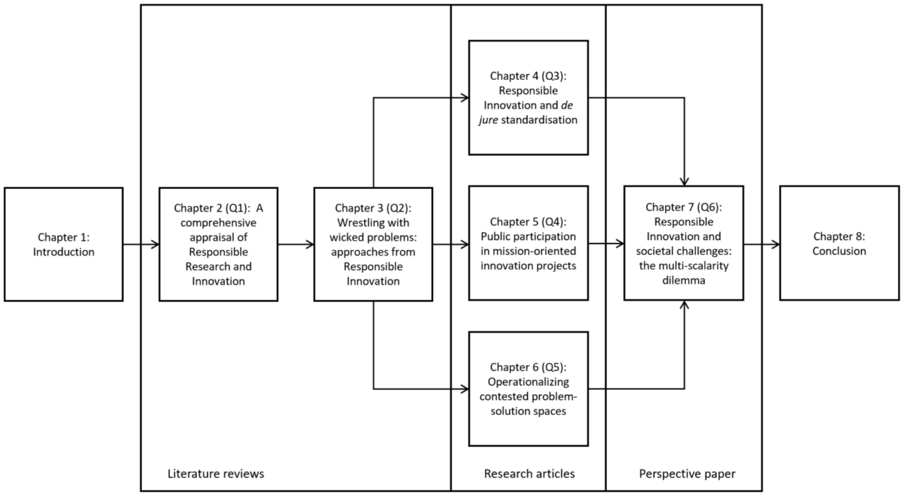

Figure 1-1: Outline of this dissertation

1.6. Detailed Outline of Dissertation

The body of this dissertation consists of six chapters that were written and submitted as independent academic papers. Despite the fact that I occasionally use the pronoun 'I' in the opening and concluding chapter of this dissertation, its research was a form of team science that was performed in close collaboration with a number of inspiring colleagues. When I refer to the overall research and dissertation, I use the singular 'I'; when I refer to the specific studies, I use the plural 'we', as this aligns with how the studies are published. Chapters 2 to 7 are identical to their published cognates. As a result, there is unavoidably repetition in content. For instance, the four procedural dimensions that form the dominant theoretical framework for Responsible Innovation – the AIRR framework – is explained in Chapters 2, 3, 4, and 7. Another case is the notion of wicked problems which is discussed in Chapters 3, 5, 6 and 7. Admittedly, some (minor) discrepancies are to be found between several chapters. In Chapter 2, for example, the reference publication year spectroscopy used for the literature review does not reveal any dominant approaches for Responsible Innovation in practice. However, the more rigorous thematic analysis used in Chapter 4 shows that several approaches such as Technology Assessment (TA) and engagement approaches are used substantially more than other approaches. A possible explanation for this discrepancy is that the great variety in these approaches (e.g. constructive TA, participatory TA, and health TA) causes authors to cite different references while roughly referring to the same 'family' of approaches.

In what follows, the abstract of each paper has been added to clarify the aim, research method, and contribution of each chapter.

Chapter 2: A Comprehensive Appraisal of Responsible Research and Innovation: From Roots to Leaves

Published in: *Technological Forecasting & Social Change*, 172, 121053
This is a joint publication with Geerten van de Kaa, Emad Yaghmaei, and Neelke Doorn.

Responsible Research and Innovation and Responsible Innovation, as academic endeavours, have grown substantially since their birth in the previous decades. They have been used as synonyms on a structural basis, and both concepts have been studied from various disciplinary backgrounds. This paper identifies Responsible Research and Innovation's and Responsible Innovation's shared research topics, knowledge base, and academic organisation as a common ground for scholars to further their individual or joint research. It does so by conducting a keyword analysis and a collaboration analysis, combined with a reference analysis of their academic literature. This paper discusses the most influential references in chronological order and sheds light on the accumulation of knowledge. The results suggest that Responsible Research and Innovation and Responsible Innovation have matured into an increasingly cumulative and interconnected research trajectory following the footsteps of similar, more mature research areas.

Chapter 3: Wrestling with Wicked problems: Approaches from Responsible Innovation

Status: unpublished manuscript
This is a joint manuscript with Geerten van de Kaa, Emad Yaghmaei, and Neelke Doorn.

Responsible Innovation is frequently framed as a promising research stream to address societal challenges. It is associated with various approaches that may allow for the socially desirable development of challenge-led innovations. However, in establishing and using these approaches, scholars have overlooked the inescapable conditions that make these societal challenges wicked. This systematic literature review examines whether Responsible Innovation is able to meaningfully respond to wicked problems and identifies and evaluates Responsible Innovation approaches against methodological conditions that rest on the underlying dimensions of these problems. The analysis reveals various potential strengths and weaknesses of Responsible Innovation in relation to wrestling with societal challenges. Overcoming these drawbacks requires us to improve, combine, or reimagine approaches that have a greater shot at addressing challenges responsibly.

Chapter 4: Responsible Innovation and De Jure Standardisation: An in-depth Exploration of Moral Motives, Barriers, and Facilitators

Published in: *Science and Engineering Ethics,* 28, 65

Presented at*: SOONS, 2020; SOONS, 2022*

This is a joint publication with Geerten van de Kaa, Neelke Doorn, and Emad Yaghmaei.

Standardisation is increasingly seen as a means to insert ethics in innovation processes. We examine the institutionalisation of Responsible Innovation in de jure standardisation as this is an important but unexplored research area. In de jure standardisation, stakeholders collaborate in committees to develop standards. We adopt the anticipation, inclusion, reflexivity, and responsiveness Responsible Innovation framework as our theoretical lens. Our study suggests that responsible standardisation processes should embody forms of these four dimensions. We investigate the institutionalisation of these dimensions and identify 96 factors that can motivate, hinder, or facilitate responsible standardisation. Factors were found through in-depth interviews with managers of a standard developing organisation. These are subsequently validated/rejected using surveys completed by committee representatives. The results suggest that the social desirability of standards is not self-evident. This study could pave the way for future research on responsible standardisation processes, complementing research on legitimacy, Responsible Innovation, and standardisation.

Chapter 5: Public Participation in Mission-Oriented Innovation Projects

Published in: *Technological Forecasting & Social Change*, 191 ,122538

Presented at: *EU-SPRI, 2022; NetSurvey, 2022*

This is a joint manuscript with Vladimir C.M Sobota, Matthijs J. Janssen, Geerten van de Kaa, Emad Yaghmaei, and Neelke Doorn.

Mission-oriented innovation policy is currently gaining renewed interest as an approach for addressing societal challenges. One of the promises is that missions can mobilize and align diverse stakeholders around a shared goal. Recent literature underlines the importance of public participation (e.g. municipalities and civil society organisations) in the socioeconomic transformations required for attaining missions. We ask how public participation differs among (non-)mission-oriented innovation projects. Drawing on a database containing Dutch government-funded innovation projects, we investigate whether mission-oriented projects are associated with *earlier*, *more open*, and *more influential* forms of public participation than conventional projects. Although the results suggest that mission-oriented projects indeed correspond with earlier participation of more public actors, we find little evidence that they also coincide with increased diversity and financial influence of public participants. We conclude by discussing how policymakers and intermediaries may engage in strategies to make missions more inclusive.

Chapter 6: Operationalizing Contested Problem-Solution Spaces: The Case of Dutch Circular Construction

Published in: *Environmental Innovation and Societal Transitions*, 48, 100752

This is a joint manuscript with Tom B.J. Coenen and Neelke Doorn.

In shaping collective responses to societal challenges, we currently lack an understanding of how to grasp and navigate conflicting ideas on societal problems and potential solutions. The problem-solution space is an increasingly popular framework for conceptualizing the extent to which problem-oriented and solution-oriented views are divergent. However, this reflexive framework needs an operationalization to become useful in practice. We contribute to this debate by demonstrating how Q-methodology can be used to systematically identify, describe, and compare collectively held visions in relation to problems and solutions. We use the case of Dutch circular construction, and identify three conflicting imaginaries that inform us about disagreement and common ground. We conclude by discussing how policymakers can use different approaches to navigate contestation, presumably mobilizing actors for a collective response.

Chapter 7: Responsible Innovation and Societal Challenges: The Multi-Scalarity Dilemma

Status: under review

This is a joint manuscript with Neelke Doorn.

Societal challenges tend to be characterized by their multi-scalarity as problems emerge and co-evolve on multiple scales. Resolving these challenges requires innovators to navigate often conflicting considerations between multiple scales when dealing with complexity, uncertainty, and contestation. Innovators need to ground resolutions in local values and worldviews while simultaneously fitting these into global efforts to help drive systemic responses. Nevertheless, studies on Responsible Innovation commonly focus exclusively on a local or global scale. In this perspective paper, we explore rationales for these two prevalent but opposing approaches, and provide tentative insights into how multi-scalarity could be navigated by uniting scales through a hybrid approach. The paper proceeds by opening up research on multi-scalarity, and the geographical and relational aspects of Responsible Innovation in a broader sense.

2. A Comprehensive Appraisal of Responsible Research and Innovation: From Roots to Leaves[4]

2.1. Introduction

Responsible Research and Innovation (RRI) and Responsible Innovation (RI) have gained increasing attention since their births in the previous decades (Owen et al., 2012; Owen and Pansera, 2019; Rip, 2016). They are often described as inclusive and risk mitigating approaches to research and innovation (R&I) activities in the process of wider techno-socio-economic transformations. The European Commission and a number of researchers expect that RRI can help to address the 'grand challenges' of society and create sustainable economic growth while minimising negative externalities of R&I (Von Schomberg, 2013). RRI as an academic endeavour is supported by the European Commission through its European Framework Programmes to better comprehend this approach, understand its implications, and potentially institutionalise this into our society (de Saille, 2015; Zwart et al., 2014). While RRI has largely flown out of the European policy domain (Owen and Pansera, 2019), RI stems from a longer tradition of science and technology studies (STS) and ethics and is thereby both an old and new concepts (Stilgoe et al., 2013). It can thus be argued that RI is a rather bottom-up research stream while RRI stems from a top-down vision (Loureiro and Conceição, 2019). Throughout both their existences, they have been criticised, opposed, endorsed, and transformed from a variety of academic perspectives (Blok and Lemmens, 2015; de Hoop et al., 2016; Macnaghten et al., 2014; Nordmann, 2014; Stilgoe et al., 2013). As a result, their respective academic landscapes have grown significantly (Burget et al., 2016; Ribeiro et al., 2017). While RRI and RI are now often used as synonyms, some scholars argue that they remain different concepts (Owen and Pansera, 2019). This has caused confusion in an already multidisciplinary and complex dialogue.

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Over five years ago, a few scholars attempted to create clarity in RI's and RRI's 'academic jungle' by conducting literature reviews (Blok and Lemmens, 2015; Burget et al., 2016; de Saille, 2015; Owen et al., 2013; Randles et al., 2015; Ribeiro et al., 2017; Timmermans, 2017; Zwart et al., 2014). Thereafter, scholars have attempted to link RRI and RI to specific topics (Martinuzzi et al., 2018; Thapa et al., 2019) or to review its institutionalisation (Genus and Iskandarova, 2018). More recently, Fraaije and Flipse (2020) have provided a review in which RI is named 'RRI's cognate'. However, Shanley (2021) and Smolka (2020) subsequently argue the contrary, and introduce the term R(R)I to emphasise their shared community while appreciating their differences. However, few authors explicitly consider the different origins of RRI and RI. And while their interaction could be academically and practically promising, it may still be worthwhile to explore what the two concepts have in common and whether we should leave room for differences as well. If their relationship is to be of value, then it is important to identify their common ground intellectually (theoretical) as well as organisationally (collaborative) for future research agendas and inbreed. No recent review has reliably identified the shared knowledge base of these fast growing academic communities nor have they assessed the vast evolution of their knowledge. This is plausibly the case due to a lack of available and reliable bibliometric tools and a lack of complete databases. These hurdles have now been overcome by the development of a relatively novel scientometric method called a reference publication year spectroscopy (Marx et al., 2014), which allows scholars to quantitatively identify the foundational knowledge on which RRI and RI rely.

This study aims to identify the shared foundation of the RRI and RI literature, and crudely assesses their overlapping topics of interest, collaborative development, and overall maturity based on a mixed quantitative-qualitative reference (bibliometric) analysis.

This paper contributes to the literature in several ways. First, it examines RRI's and RI's growth and cognitive- and collaborative developments, to subsequently reveal the conceptual state in which they find themselves. Second, by doing so, it creates awareness of RRI's and RI's academic organisation and shared literature as a starting point for promising future research directions and as input for a collective and consentaneous research agenda. Generally, such a consensus would aid in achieving a greater knowledge accumulation (Evans, 2007).

2.2. Method

2.2.1. Data collection

As input, we collected publication metadata from the database Web of Science (WoS). All titles, author keywords, keywords plus®, and abstract words of English articles published between 2010 and 2019 containing 'responsible research & innovation', 'responsible research and innovation', or 'responsible innovation' have been retrieved. The respective time period has been chosen since 2010 forms a turning point that marks the upsurge of publications produced on the topics (Thapa et al., 2019). In addition, 2011 and 2013 are generally considered to be important years for RRI's and RI's development due to influential contributions of Von Schomberg (2011) and Stilgoe et al. (2013). It thus allows us to take stock of the fields before and after these publications. Our data collection resulted in a sample of 508 articles (Table 2-1).

Table 2-1: Document types in the collected sample from the WoS.

Document types	N.
Articles	449
Articles, Book chapters	45
Articles, Early access	11
Articles, Proceeding papers	3

2.2.2. Data analysis

We analysed the articles by using the open-source R-package of Aria and Cuccurullo (2017) named Bibliometrix, which assists the data collection (loading and converting), analysis, and visualisation[5].

We used a keyword and a collaboration analysis as a bibliometric assessment to capture the cognitive and collaborative developments. Furthermore, we conducted a reference analysis to identify the shared knowledge base of RRI and RI as input for the review of the literature (Figure 2-1).

5 The Bibliometrix visualisation process is further supported by the tool VOSviewer.

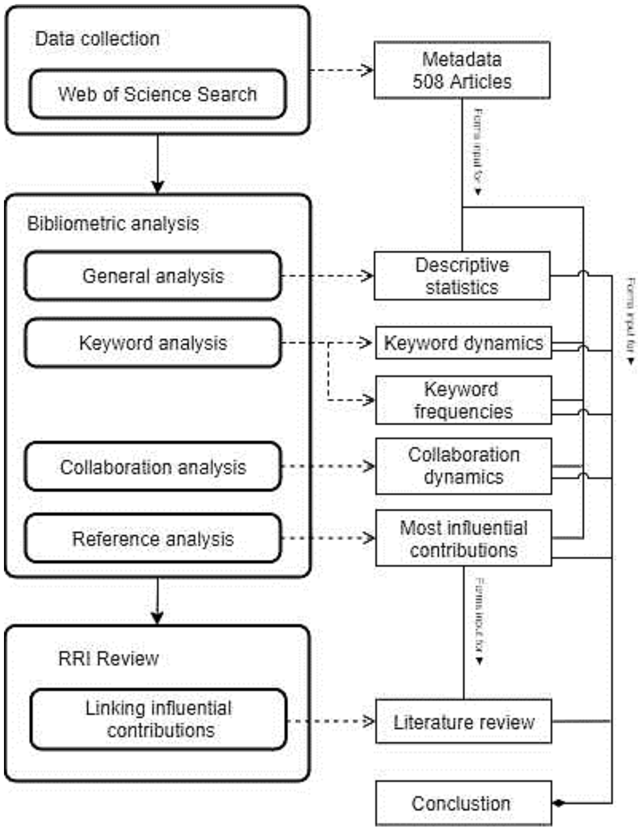

Figure 2-1: Process-deliverable diagram of research method

Cognitive and collaborative developments

Cognitive and collaborative developments were analysed by conducting a co-word analysis (Callon et al., 1983) and a co-author analysis (Newman, 2004; Subramanyam, 1983; White and McCain, 1998). Both analyses are constructed by connecting author keywords or co-authors that return in the same document, resulting in the clustering and mapping of keyword and co-author structures in the form of networks. Hence, a sequence of annual networks provides insight in RRI's and RI's evolution. The sequence of keyword co-occurrence networks provides insight in the cognitive evolution through the semantics of author keywords. It additionally, provides insight in the way RRI and RI are, and are not, connected content wise. The co-author collaboration network visualises the evolution of the explicit academic collaborations and therefore provides information about the academic organisation of RRI and RI. Moreover, collaborations can stimulate the exchange of (tacit) knowledge (Katz and Martin, 1997) and by doing so, trigger further cognitive progression and interconnectedness (Phelps and Heidl, 2012). The years 2010, 2015, and 2019 have been visualised in this paper to illustrate their overall evolution in the past decade.

Reference analysis: RRI's and RI's common foundations

This study makes use of a reference publication year spectroscopy (RPYS) (Marx et al., 2014; Thor et al., 2016). This quantitative reference analysis method identifies the most influential contributions found in the reference lists of the 508 RRI and RI publications. In other words, the RPYS identifies the shared knowledge base of RRI and RI which has functioned as the foundation for their academic contributions. The method maps the data spectroscopy by computing the number of cited references per publication year of the 508 publications. Subsequently, it computes the deviation of each publication year from a 5-year median period to reveal the years that are cited exceptionally well relative to its time. Within the given year, the outlying references needed for the historical overview are then provided. The RPYS is further supported by a manual check on anomalies in most recent years (2010-2019) to ensure the inclusion of more recent influential contributions in which citation distributions are less skewed, and hence in which deviations are less obvious.

The RPYS has become an increasingly popular method for the identification of a topic's historical roots, and has been used in various fields (e.g., Khasseh and Mokhtarpour, 2016; Moral-Muñoz et al., 2020). This method has several benefits. (1) It recognises anomalies in the reference citation distributions relative to its time. Moreover, (2) it helps scholars to objectively and quantitatively find influential knowledge (3) in any explicit form (articles, book chapters, reports, etc.) that (4) did or did not return in the WoS database, and (5) that was significant to RRI's and RI's community as opposed to science in general (i.e. cited by RRI and RI articles vs cited by articles in general). Identifying these sources is crucial as the literature of interest generally contains many citations to non-journal papers, particularly in the period before the launch of the *Journal of Responsible Innovation* in 2014.

2.3. Results

2.3.1. Bibliometric analysis

Descriptive statistics

The sample of 508 RRI and RI articles were published in 217 different sources, contained 1387 unique keywords, and was cited on average 8.9 times. To avoid confusion between the keywords provided by the authors and the words distilled from the title and the abstract, we refer to the former as the author keywords. This study found 1556 unique authors. The number of authors and articles increased consistently throughout the period (Figure 2-2). The graph shows how RI was more prevalent in the literature until 2016. In more recent years, RRI has grown to become a topic of academic concern of a similar magnitude.

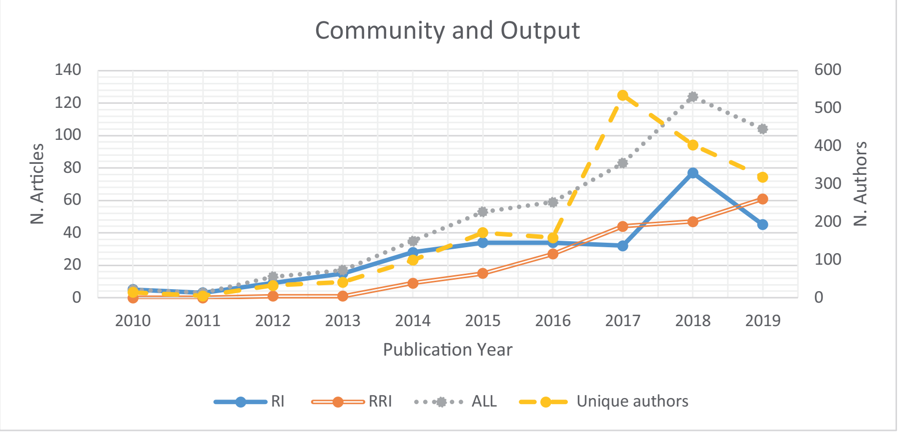

Figure 2-2: Academic community size & output

Keyword analysis

Our keyword analysis aims to establish a semantic representation of RRI and RI. The most frequently used keywords, abstract words, and title words of RRI, RI, and the total sample can be found in Appendix A. Bibliometrix extracts terms and neglects stop words for abstract words and title words. The results show that RRI and RI predominantly focus on the governance and ethics of research and innovation. Industry related terms such as 'corporate social responsibility', 'industry' and 'management' score relatively low and could have received less attention. In addition, only 31 of the 508 articles contain the word 'case', suggesting a relatively small proportion of case studies, which seem to have been done more for RI than RRI. The keyword co-occurrence networks of 2010, 2015 and 2019 (Figure 2-3) show that RRI and RI have gradually evolved and merged into interconnected clusters. Before the introduction of RRI (Von Schomberg, 2011), the network mainly consisted of RI driven research (see the upper left panel in Figure 2-3, showing the results for 2010). The network suggests that RRI has eventually situated itself in the RI literature. The topics 'public engagement', 'governance', 'emerging technologies' (e.g. nanotechnology and synthetic biology), and 'ethics' form the locus of their overlap.

The 2019 network suggests that topics such as ‘public engagement’, ‘governance’, ‘anticipatory governance’, and ‘social innovation’ have received increased attention along other rooted topics such as ‘ethics of research’ and ‘science and technology policy’. Weakly connected clusters visualised by network gaps and branches could indicate potential research opportunities. Some examples of this relate to ‘education’, ‘big data’, and the ‘broader impact’.

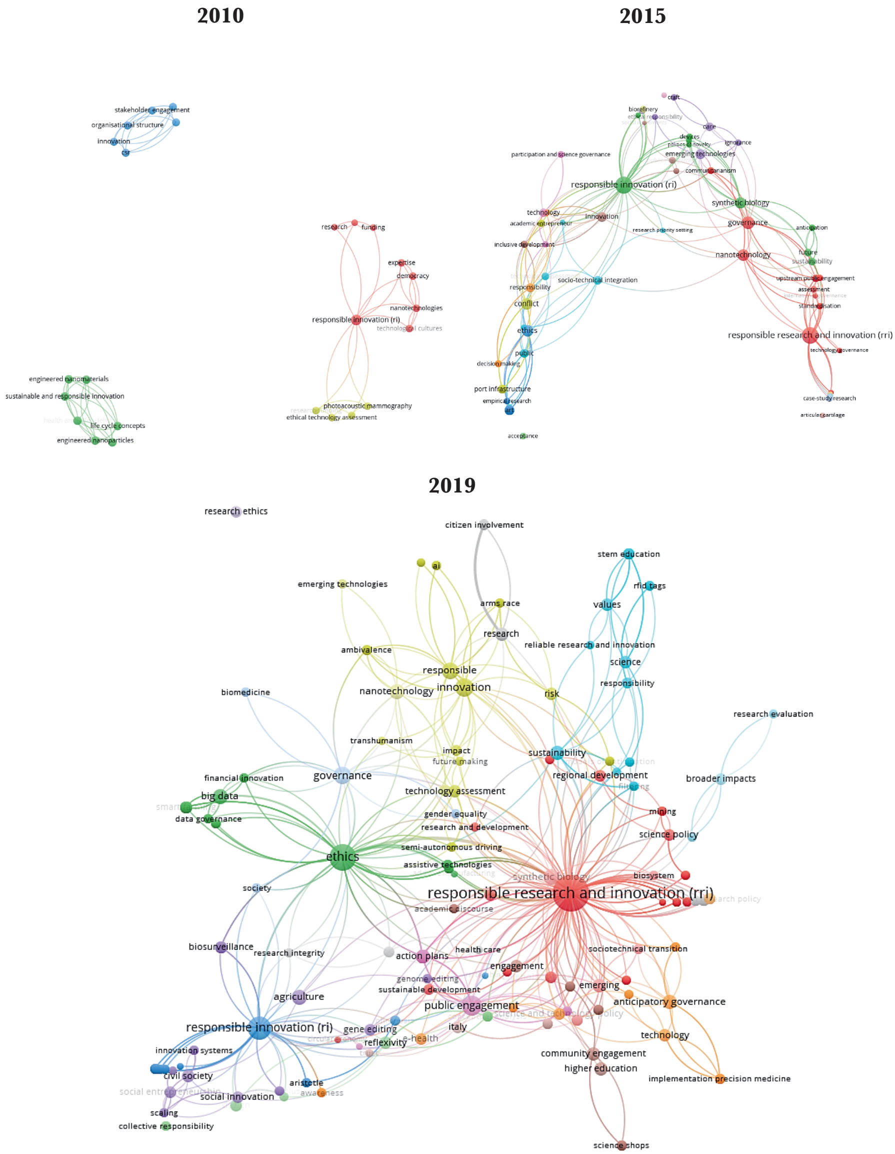

Figure 2-3: Keyword co-occurrence networks (2010, 2015, 2019). Note: Nodes represent topics, and links represent the co-occurrence of topics in articles. Synonyms for Responsible Innovation (e.g. RI) and for Responsible Research and Innovation (e.g. RRI) have been aggregated to visualise the network more clearly.

Collaboration analysis

This study uses a co-authorship analysis to assess the collaborative developments in RRI and RI. The author collaboration networks in figure 2-4 show collaborations in the year 2010, 2015, and 2019 to illustrate the overall evolution of RRI's and RI's community. The first period was characterised by just a few isolated author groups dedicated to RI. The network has grown throughout the decade with the appearance of more authors and clusters. However, the network density decreased, indicating that many scholars work in isolated research groups. The majority of large clusters represent single papers published by a large number of, often EC funded, co-authors. For example, the dominant red cluster in 2019 is the result of a single article written by 39 authors from various organisations working on the STARBIOS2 project funded by the EC (Colizzi et al., 2019). Few authors in the network have taken in broker positions to mediate between clusters, and as a result, inter-cluster collaborations are rare. Collaboration statistics in Table 2-2 suggest that the percentage of inter-organisational collaborations has fluctuated around 50%, but does not show a consistent trend.

Overall, there have been frequent academic (inter-organisational) collaborations. However, few inter-cluster collaborations take place. As a result, many scholars work in small isolated groups. The few larger groups are often the result of one single multi-authored paper.

Table 2-2: Collaboration statistics.

	2010	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**
Article count	5	3	13	17	35	53	59	83	124	104
N. multi-author articles	3	2	7	10	27	34	41	70	98	71
% multi-author articles	60%	67%	54%	59%	77%	64%	69%	84%	79%	68%
N. single-author articles	2	1	6	7	8	19	18	13	26	33
Mean authors per articles	2.8	1.7	2.5	2.8	3.7	3.3	2.7	6.5	3.3	3.1
Mean collaboration size	4.0	2.0	3.7	3.4	3.4	4.5	3.4	7.5	3.9	4.1
N. international collaborations	2	0	5	5	12	18	12	24	30	22
% international collaborations	40%	0%	38%	29%	34%	34%	20%	29%	24%	21%
N. inter-organisational collaborations	3	0	5	9	18	25	27	45	63	43
% inter-organisational collaborations	60%	0%	38%	53%	51%	47%	46%	54%	51%	41%

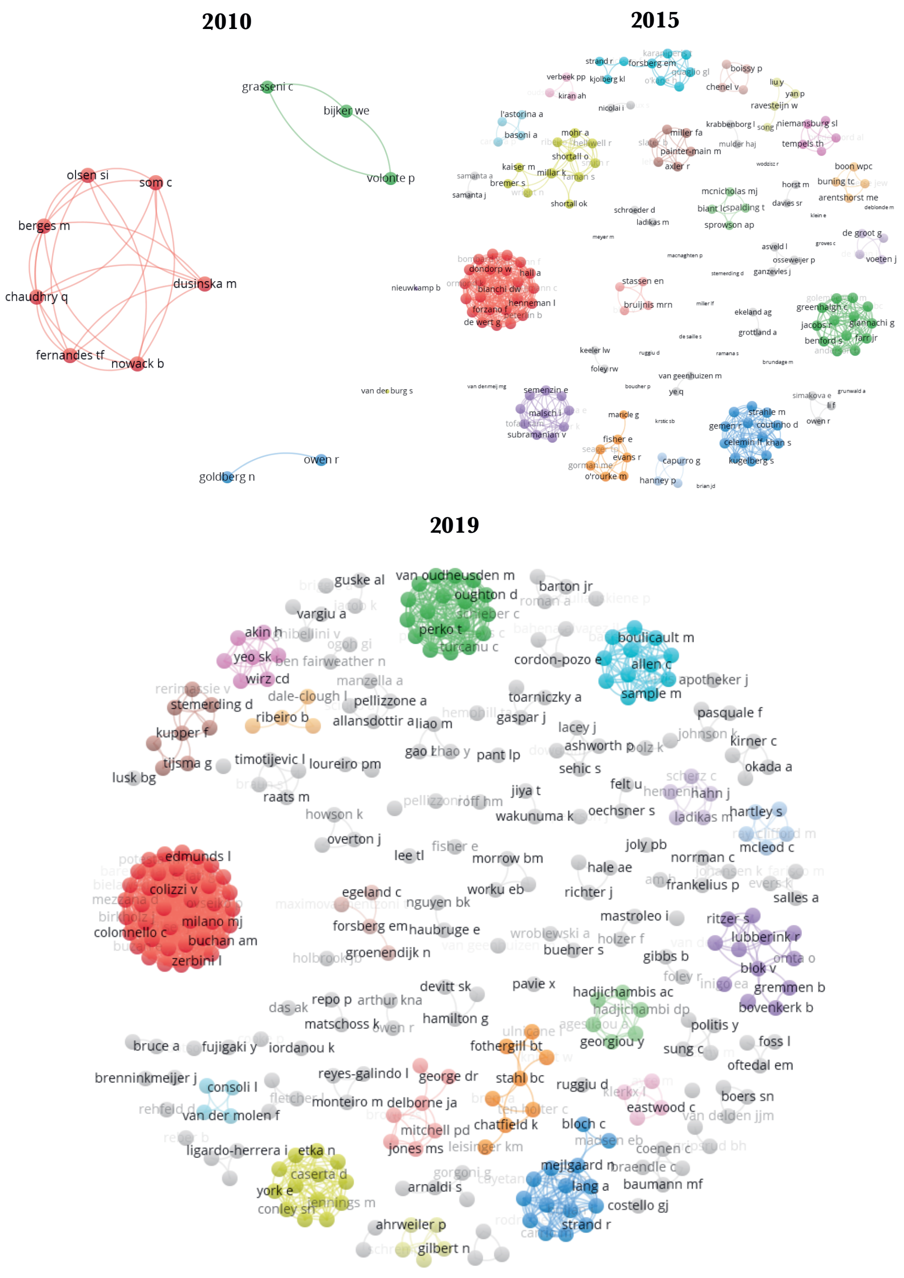

Figure 2-4: Author collaboration network (2010, 2015, 2019). Note: Nodes represent authors, and links represent collaborations through co-authorships.

2.3.2. RRI's and RI's common foundations: a chronological overview

The earliest documents to be cited by RRI's and RI's body of literature were written by historical writers such as Francis Hutcheson (1725), Adam Smith (1776, 1759), David Hume (1777), Jeremy Bentham (1781), and Immanuel Kant (1787, 1785). RRI's foundation thus lays predominantly in (moral) philosophy with early on links to sociology and economics. Schumpeter (1934) eventually strengthened links to economics. He introduced the concept of 'creative destruction' and is arguably one of the first to elaborate on the significant economic, if not societal, effect that can be brought about by innovation. Several years later Bernal (1939) analysed the link between science and socioeconomic development, hence, pioneering 'responsible research' through linking science with morality by underlining scholars' broader societal impact. His view that scientists should establish stronger linkages with public affairs was considered to be controversial.

Science for society?

This discourse eventually found itself increasingly more in the context of warfare. Bush's (1945) report, Science, The Endless Frontier, solicited for a more centralised control of (basic) science in which a scholar's curiosity and the societal demand would meet. The report highlighted the government's responsibility for the progress of the nation, if not mankind. The devastating nuclear attack on Japan two weeks after the report was published, and the success of recent scientific breakthroughs (e.g. radar and penicillin) contingently enforced the message and drastically changed research policy. According to Charles Lindblom (1959), this synoptic approach of decision-making in US post-war policy practices was, in reality, less systematic and controlled ex ante than it seems. Lindblom suggested that policymakers were 'muddling through' due to their 'bounded rationality' resulting in non-comprehensive policy analyses and plans. He argued that it exemplified incrementalism, which here refers to an evolutionary public policy trajectory in which minor policy changes are designed and implemented in a gradual manner to attain a greater societal change. This is a process of trial-and-error in which one uses experience as input for future practices. Parallel to this policymaking debate, Michael Polanyi, provided a seemingly incompatible view with Lindblom's in his essay, The Republic of Science: Its Political and Economic Theory (1962). He described the scientific community as a system of mutually complementary actors that independently work on scientific initiatives and are focused on inter-determined intellectual objectives. It does not require external 'muddling' due to entrenched conformities, established by the constantly selfrenewing academic authorities. He calls this community 'the republic of science' and advocates for autonomous scientists primarily driven by the satisfaction of their curiosity. As Polanyi (1962) claims: 'And as they (scientists) satisfy themselves, they enlighten all men and are thus helping society to fulfil its obligation towards intellectual self-improvement' (p. 64). This call for autonomy implies a direct opposition with Lindblom's interventionist 'muddling through' policy practice, and possibly distances science from society.

That same year, Thomas Kuhn published his influential book, The Structure of Scientific Revolutions (1962), and provided a novel perspective on the progress of science. Kuhn argued that the scientific system is more complex than the, back then, prevailing perspective that knowledge develops by a consistent accumulation and thence is only incremental in nature. He explains that occasionally radical breakthroughs cause a scientific paradigm shift and form a major academic leap which creates numerous new research (and societal) opportunities. This, as Polanyi would likely agree, gives way for organisational change and the renewal of scientific authorities.

Innovation and its sociotechnical nature

After the 1950s, academic contributions were more related to innovation (management), partly elicited by Wiener's perspective on automation ethics (1954), and Everett Rogers's innovation theory (1962). Wiener was concerned with the possible and uncertain effects of automation on society and implicitly linked this to Schumpeter's creative destruction (Wiener, 1954). Rogers's theory aimed to describe and explain the process of innovation diffusion and adoption. He identified diffusion determinants and taxonomised adopter groups based on their innovativeness. Wiener and Rogers thence pioneered the relationship between technology, sociology, and economics. Collingridge (1980) theorised that attempting to control a technology is difficult because its future trajectory, impact, and externalities cannot be accurately predicted during its early stages. However, controlling it ex post is increasingly troublesome when the above-mentioned outcomes become more fixed and noticeable. These impacts and externalities can take on political forms according to Winner (1980). He argued that technologies can (un)intentionally embody norms and values which can enforce power structures, systems, sources, and ideologies. In a similar vein, Jonas (1984) advocated the need for a halt on society's reinforced techno-political system. This was motivated by his perception that the need for everlasting economic growth through technological progress was steering civilisation on a destructive path, creating a fatal reciprocal relationship between society and the environment. Concurrently, von Hippel (1988) identified the democratisation of innovation through his concept of user innovation. He observed that in some industries, users, not manufacturers, were responsible for a substantial number of innovation practices. Users are cognitively distant from manufacturers and exhibit personal 'sticky' knowledge that manufactures do not possess. This information asymmetry forces some users to innovate in order to meet their own demands.

Reflexive modernity, technology assessment, anticipatory governance, and more

The sociologist Ulrich Beck (1992) took a different angle. He focused on the concepts of risk society and reflexive modernity. Risk society refers to the fundamentally different way modern society responds to anticipated risks, whereas reflexive modernity is described as a recent societal condition in which modern civilisation reassesses and shapes itself. At around the same time, Rip, Schot and Misa (1995) introduced Constructive Technology Assessment (CTA). CTA developed out of a longer tradition of technology assessment, focusing on including a wider set of stakeholders in the anticipation of plausible consequences of new technologies and technological developments (Schot and Rip, 1997). As such, they linked Beck's risk society to participation in decision-making on technological risks. Rowe and Frewer (2000) extended the topic of inclusive anticipatory approaches by evaluating public participation frameworks more holistically. They argue that both the process and acceptance of participatory decision-making should be considered for the selection of situational appropriate participation methods. Guston and Sarewitz (2002) developed real-time technology assessment as a more suitable tool for the continuously co-evolving sociotechnical decision process. Barben et al. (2007) advocated the need for more varied methods, materials, ideas, theories, etc. (referred to as research ensemble by Hacket et al., 2004) from a wide range of researchers and policymakers inside and outside of the relevant field of interest. Barben et al. (2007) argue for the integration of these research ensembles in Guston and Sarewitz's (2002) concept of anticipatory governance. This 'ensemble-isation' forms the core practice of anticipatory governance. It goes further than anticipation simpliciter, as it includes empirical studies and analytics, and explicitly embraces imagination, uncertainty, and the proclivity to gain insight from experimentation.

In the first decade of this century, methods related to responsibility and ethics gained traction especially in the field of nanotechnology. Although nano-ethics questions were considered, it was argued that the broader New and Emerging Science and Technology (NEST) ethics might be more fruitful. NEST ethics addresses the emerging technology's uncertainty regarding its future capabilities, their implications, and the revision of moral routines in the light of this new technology. Hence the dynamics and interactions of these aspects caused a co-evolution of the technology and its corresponding ethics (Swierstra and Rip, 2007). Erik Fisher (2007) conducted a case study on this co-evolution in the field of nanotechnology by incorporating a real-time assessment of research practices, attempting to enhance the reflexivity of scientists. He noticed that an increased reflexivity could lead to room for negotiation about research practices, and hence to alternative decisions. More case studies that integrated ethics in research and innovation activities followed (Owen and Goldberg, 2010; Robinson, 2009; Schuurbiers, 2011). Notable is Robinson's (2009) contribution for introducing the terms RRI and RI for the first time in one academic article.[6]

RRI as a framework

In the meantime, the European Commission sensed the need for a change in the scientific system (Felt et al., 2007; Sutcliffe, 2011; Von Schomberg, 2011). It was evident that the previous decades had caused public unease with science-based technologies and that there was a need for further democratisation of science and governance and for solutions to societal challenges. The EU moved from risk governance to innovation governance with a stronger emphasis on civic engagement. This could spur (risk mitigating) innovations, stimulate the knowledge economy, while simultaneously increasing the credibility of the scientific system (Felt et al., 2007; Sutcliffe, 2011). Credibility of public participation and engagement depends on the underlying competing rationales (i.e. normative, substantive, or instrumental) and the respective power positions of associated actors. The normative rationale concerns the 'right thing to do', without considering its implications per se. Contrarily, a substantive rationale is motivated by the outcome and implications. Lastly, an instrumental imperative adheres to the outcome as well, but is little linked to broader societal values, but rather to the actor's own pursuit (Stirling, 2008).

The European Commission supported 'Science in Society' programme (FP7), which embodied the initial centralised response to the above-mentioned challenges. In the context of this programme, Von Schomberg (2011) provided the first

6 Brundage and Guston (2019) state that the term RI is introduced earlier, but the RPYS found these contributions not to be influential enough for RRI/RI's contemporary discourse to be included in this review.

contemporary definition of RRI: 'Responsible Research and Innovation is a transparent, interactive process by which societal actors and innovators become mutually responsive to each other with a view on the (ethical) acceptability, sustainability and societal desirability of the innovation process and its marketable products (in order to allow a proper embedding of scientific and technological advances in our society)' (p. 9). This is thus a definition from an inherently European Union context with an emphasis on ethical acceptability, sustainability, and societal desirability. These normative dimensions originate from the EU's fundamental values (rights and safety), its sustainable development objectives (economic, social, and environmental), and the Treaty of the European Union (quality of life, equality, etc.) (Von Schomberg, 2014, 2013, 2011). In addition to this definition and normative ends, he provided a vision on what RRI should not be. Irresponsible research and innovations are classified as practices and outcomes resulting from an (often single) actor that is unaware of the social environment or unable to resolve its respective conflicts. Although Von Schomberg suggested an RRI definition and its normative ends, he recognised that there was no consensus on these, nor was there an agreed approach on how to institutionalise the concept into practice (Owen, 2014; Von Schomberg, 2013). Owen, Macnagthen, and Stilgoe (2012) were one of the first to recognise a broader trend in policy and academia towards this new concept (2012). Stilgoe et al. (2013) argued that the RRI definition and focus areas of Von Schomberg's European perspective might not be in line with the values of other cultures and other areas of innovation. Instead they develop a prospective notion of responsible innovation that draws from governance developments and integrates responsibility on a purpose and process level as opposed to conventional modes of governance that merely emphasis the (right) outcomes of research and innovation processes. They stated: 'Responsible innovation means taking care of the future through collective stewardship of science and innovation in the present' (Stilgoe et al., 2013, p. 1570), and placed 'anticipation', 'reflexivity', 'inclusion', and 'responsiveness' as central interconnected dimensions in their framework.

'Anticipation' of research and innovation requires actors to raise the 'what if…' question (Ravetz, 1997) and is concerned with possible broader impacts and their probabilities. Foresight, (constructive) technology assessment, and scenario planning are examples of methods that serve this dimension. 'Reflexivity' urges actors to transparently assess the alignment of their role and their moral responsibility. Examples are codes of conduct, moratoriums, and the introduction of social scientists and ethicists in research and innovation practices. 'Inclusion' relates to the wider participation of actors and in particular the proactive, early, and genuine seizing of diverse forms of perspectives, feedback, and other forms of information. It is hence in line with the more widely accepted and adopted notion of open innovation (Chesbrough, 2003). Focus groups and citizens' juries are examples of appropriate tools. 'Responsiveness' requires the capability of actors to steer research and innovation trajectories in reaction to new information through e.g. niche management, regulation, and standards (Stilgoe et al., 2013). The above-mentioned umbrella terms can embody a diverse gamut of mechanisms of which its usability is context dependent. This research ensemble of various dimensions and its respective mechanisms can be mutually reinforcing, as well as conflicting. Increased inclusion, for example, might lead to greater reflexivity and more effective anticipation (Stilgoe et al., 2013).

RRI and RI: From concepts to emerging research trajectory

To further strengthen RI, Guston et al. (2014) recognised a need for a new, dedicated, and inclusive journal that could help to nurture and communicate this endeavour. They presented the *Journal of Responsible Innovation (JRI)*, as a centralised channel to 'articulate and discuss the many unsolved questions surrounding RI' and invite 'new and surprising perspectives from scholars and practitioners who take an interest in reflecting on and debating RI' (p. 3).

According to Van Oudheusden (2014), some of these unsolved questions relate to the seemingly non-political nature of RRI/RI while, in reality, its deliberation is inherently linked to politics. He highlights the paradox that 'no one actor is in control, but everyone is implicated, has agency and therefore is responsible, interconnected in complex networks, at multiple scales and in numerous ways' (Van Oudheusden, 2014, p. 196). This view emphasises the need for a better understanding of systems and their power distribution. The author pleads for a higher RI-politics proximity and for greater comprehension of its institutional side. The discourse should not merely deal with responsibilities of single actors, but also the (ir)responsibilities associated with, and induced by, systemic structures. This raises the question of how structures can be altered, and thus how RI processes can actually be designed and integrated to induce institutional change (Macnaghten et al., 2014). In addition, early on, some scholars identified that RRI and RI were largely built upon, or in, the northern (especially European) socio-political context (Owen et al., 2013; Rip, 2016; Stilgoe et al., 2013;

Wong, 2016) and might be disconnected from other political, cultural, or economic circumstances and practices (Macnaghten et al., 2014; Wong, 2016). A more local and contextual deployment of responsibility in innovation is required, which should also take into account its relationship with less high-tech focused innovations (e.g. social innovation) which, in some cases, might be more relevant for less developed regions (Bock, 2012).

Lubberink et al. (2017a, 2017b) compared RI and social and sustainable innovation and concluded that although these ambiguous concepts overlap to a certain extent, they are different. Social innovations are predominantly concerned with creating social value while sustainable innovations are aimed at integrating conservation and development. RI predominantly distinguishes itself through the ethical reflection on relevant norms and values and makes use of a variety of sociotechnical integration approaches to do this (Fisher et al., 2015). And although social and sustainable innovation have made their way into practice, it is highly questionable whether RRI and RI can attain the same. Their implementation, in its most ideal form, seems somewhat unrealistic according to various authors (Blok and Lemmens, 2015; de Hoop et al., 2016; de Saille, 2015; Nordmann, 2014; Van Oudheusden, 2014). For instance, RI's democratic governance and deliberative engagement of research and innovation in the industry appears unattainable due to actors' information asymmetries upon which many firms rely for their competitive advantage (Brand and Blok, 2019). Moreover, actors are realistically limited in the number of stakeholders they can include in their practices (Lubberink et al., 2017b). The associated mutual responsibility is questionable due to the different risks (and potential gains) they share (Blok et al., 2015; Blok and Lemmens, 2015). The motives, goals, power, and visions of actors are heterogeneous, which challenges collective responsiveness, co-responsibility, and coordinated interaction (Raman et al., 2014; Stirling, 2008; Taebi et al., 2014; Thapa et al., 2019; Van Oudheusden, 2014). Hence, some scholars favour a more realistic and pragmatic modification of RI's framework and plead for more research on its implementation, its effectiveness ,and its eventual institutionalisation in industry (Blok et al., 2015; Blok and Lemmens, 2015; Brand and Blok, 2019).

Several case studies have been conducted in an attempt to implement RRI/RI approaches and reflect on their implications (Aicardi et al., 2018; Iatridis and Schroeder, 2015; Owen and Goldberg, 2010; Schuurbiers, 2011; Stahl et al., 2017). At the same time, policymakers are urged to make explicit commitments to RRI/RI through policy experiments considering the valuable experiences it will provide (Balmer et al., 2016; Owen, 2014) for, what Lindblom called, the process of 'muddling through' (1959). The learning process is undeniably an essential component in anticipatory governance (Guston, 2014; Owen et al., 2013), and in RRI/RI in general. It could, for example, provide valuable lessons on how to facilitate inclusive processes (Taebi et al., 2014) and further strengthen additional rationales needed for wider public participation (Stilgoe et al., 2014). This can provide rich information on the values of stakeholders and lead to an increased acceptance of innovations, although this is influenced by the way innovations are framed to the public (Boucher, 2015). Guston tried to expand the discourse of inclusion and broader anticipatory governance (2014). He argues that the inclusion of formerly excluded actors might not mitigate all negative impacts but could lead to slight adjustments of the innovation (process) towards the 'right impacts'. Similar to Nordmann's (2014) view, this is a more nuanced expectation of anticipatory governance, and arguably of RRI/RI in general.

In conclusion, throughout history, the academic discourse evolved from 'if' science should be governed to 'how' this should be done. After the 1950s, an increased emphasis on the nexus of innovation and science with society emerged. Afterwards, the sociotechnical nature of innovation was revealed, which followed by contributions on reflexive modernity, anticipatory governance, and technology assessment. It is from this knowledge disposition that RRI and RI arose as the result of seminal contributions such as that of von Schomberg (2011) and Stilgoe et al (2013). Furthermore, our analysis of RRI's and RI's cited references from the last decade confirms Owen's and Pansera's (2019) observation that their concepts stem from different background even though they are frequently interchangeably used. Since their introduction, RRI and RI have been heavily debated and are still facing many questions, challenges, and research opportunities regarding its implementation, evaluation, and institutionalisation. Following recent contributions that are described above, scholars seem to disagree whether RRI's and RI's can be implemented in practice in its most ideal state. Only future research will reveal how collective stewardship of science and innovation could manifest itself in R&I practices and if it can take care of the future.

2.4. Discussion

This study used a RPYS to identify the contributions that gave rise to RRI and RI research of the last decade. It revealed the knowledge accumulated on science, innovation, governance, ethics, and society on which it is constructed. Evidently, RRI and RI are heterogeneous in nature and greatly lean on both diverse fundamental, as well as, novel knowledge. Remote contributions in the past have stimulated the birth of new, often isolated, disciplines that have incrementally increased their mutual proximity over time, leading to greater theoretical coherence in the historical overview. Based on the contributions identified by the RPYS, this study finds that the term RI and RRI were first combined by Robinson (2009). However, it is only later that they became structurally interconnected topics after the seminal contributions of von Schomberg (2011) and Stilgoe et al (2013). Von Schomberg's contribution was policy oriented while Stilgoe et al's contribution was academic in nature. It seems to confirm Owen and Pansera's (2019) argument that while both topics have been introduced with different backgrounds, they have become increasingly interconnected and used frequently interchangeably. RRI and RI's structural interaction is confirmed by our keyword co-occurrence analysis. Isolated clusters of topics became increasingly interconnected and gave way for new research opportunities and combinations. In addition, as the time in-between influential years (years with citation anomalies found by the RPYS) becomes shorter when moving from the past to the present day, one can argue that the rate of (influential) knowledge accumulation has increased exponentially. With the upsurge of relevant knowledge combinations, the funding support of the European Commission, and the creation of the *JRI,* it is not surprising that RRI and RI have attracted many new scholars which have boosted the community's collective productivity.

RRI and RI are often compared with adjacent research areas e.g. (political) corporate social responsibility, (Iatridis and Schroeder, 2015; Martinuzzi et al., 2018; Van de Poel et al., 2017; Voegtlin and Scherer, 2017), and sustainable and social innovation (Lubberink et al., 2017b, 2017a). Other scholars have conducted bibliometric analyses for these adjacent fields, which allow us to roughly compare RRI's and RI's joint productivity (quantity not quality) to give us a sense of their maturity. These analyses suggest that RRI and RI together show productivity levels comparable with corporate social responsibility in 2009 (Ferramosca, 2019), social innovation in 2014/2015 (Kaya Ozbag et al., 2019), and green innovation (close to sustainable innovation) in 2008 (Albort-morant et al., 2017).

This comparable size and productivity in combination with the dramatic growth and interconnectedness of the keyword co-occurrence network presented in this paper, can be used as a strong argument that RRI and RI have grown into an increasingly cumulative research trajectory and represent a constellation of interconnected ideas. Here, RI plausibly lends a heritage of ethics and STS knowledge, while RRI provides significant funding from the EC. Their synergy moves them in the footsteps of other more mature research areas. However, most RRI and RI scholars generally seem to work in small, isolated, and increasingly national clusters. While explicit knowledge can still be exchange via traditional means (i.e., academic publications), the lack of collaboration between different clusters may limit the flow of tacit knowledge (Polanyi, 1966) and can therefore slow down the maturation of the field as a whole.

When considering our qualitative analysis, it can be concluded that the academic discourse evolved from 'if' science should be governed to 'how' this should be done. At a later stage, its link to innovation became increasingly clear. After the 1950s, the debate emphasised the nexus of innovation and science with society. The sociotechnical nature of the innovation process was exposed and gave rise to contributions on reflexive modernity, anticipatory governance, and technology assessment. It is from this knowledge composition, that the first influential RI contributions arose (Owen and Goldberg, 2010; Robinson, 2009). Although Robinson (2009) is the first to both mention RI and RRI in one article, the keyword co-occurrence network shows that RRI has only truly situated itself in the discourse of RI after 2010. In addition, it shows how their content interacts through topics such as public engagement in emerging technologies. Over time, RRI's and RI's research has touched and/or expanded on concepts like social innovation, anticipatory governance, ethics of research, and science and technology policy. The results suggest RI to be an adaptive and reflexive form of open innovation that embraces uncertainty through collective anticipation (process) while RRI is a normative European perspective on responsibility (outcome). The keyword analysis suggests that there are slightly more articles on RRI than RI in our sample (as can be found in the Appendix A). Although various principles of EC's '6 RRI keys' (public engagement, open access, gender, ethics, science education, and governance) return as prominent topics in research, namely public engagement, ethics, governance and science education, its seems to generally overlook principles like open access and gender.

The overview presented by this paper distinguishes itself from other historical overviews on RRI/RI (Brundage and Guston, 2019; Shanley, 2021) by relying on multiple quantitative methods (co-word analysis, co-author analysis, and RPYS) and going further back than the last decade. Utilizing such a different lens is important as the overlap and interconnectedness of RRI/RI's movements remained unclear (Brundage and Guston, 2019). The overview shows that both RRI and RI have been heavily debated since their introduction, and that they still face many questions, challenges, and research opportunities. These predominantly relate to the implementation[7], evaluation, and institutionalisation of their frameworks and values in practice. It is necessary to respond to these inquiries for both whole (innovation) systems and individual actors. This resonates with the multi-layered dynamics of responsibility (Fisher and Rip, 2013), and the collective, and role responsibility distinction (Grinbaum and Groves, 2013). The system level requires answers on how to deal with its politics, systemic barriers, sociocultural (and economic) differences, and actor interactions. It is furthermore concerned with how RRI and RI can be realised in a market-driven environment where there is unequal distribution of actors' power and responsibility, and a difference in their motives, goals, visions, and perspectives. At the actor level, some of the same challenges still apply, but additionally a great uncertainty needs to be addressed on whether (and how) industrial actors will benefit from RRI and RI practices. Some scholars are sceptical and wonder whether RRI and RI can be implemented in their most ideal state (Brand and Blok, 2019; de Hoop et al., 2016; Lubberink et al., 2017b).

2.4.1. Implications

This study found that scholars collaborate frequently, but predominately in small and isolated clusters. This can obstruct the flow of knowledge, particularly tacit knowledge. This limited exchange of knowledge can hamper RRI's and RI's accumulation and therefore limit its progress.

We would like to advocate an increase in the number of case studies. Only 31 of the 508 articles in our sample contained the word 'case'. Case studies might not always use the words 'case study', and go by different names such as 'pilot study' (e.g. Owen and Goldberg, 2010). While this is true, our results in combination with the review of Schuijff and Dijkstra (2020)[8], suggest a rather low number of case studies (particularly for RRI). This is especially valid in light of the broad, diverse, and still explorative nature of contemporary RRI and RI. Some recent examples of needed exploratory

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7 Fraaije and Flipse (2020) RRI and RI's review is a relevant contributions related to their implementation.

8 Schuijff and Dijkstra identify 52 RRI/RI case studies.

case studies are those from van de Poel et al (2020), Long et al (2020), and Oftedal et al (2019). In our opinion, case studies are vital for the identification of potential propositions that, by means of larger and more comprehensive studies, can lead up to tested RRI specific theories. More explorative research by means of case studies thus seem an area for future research.

Based on our qualitative analysis, distinct discourses from a variety of perspectives take place and address the practices of industries, governments, and public research institutes. The AIRR framework (Stilgoe et al., 2013) appears to be the most widely used conceptual framework. On the contrary, no practical approach for implementation seems to have gained clear dominance yet, as a broad spectrum of such methods is used (e.g., STIR, scenario planning, CTA). This plurality of approaches (as well as discourses, perspectives, concepts, etc.) could be explained by the heterogeneous community and the inherently context-dependent, but broadly applicable nature of RRI and RI. This in combination with the affiliated core framework of Stilgoe et al. (2013), which operates at a higher abstraction level, gives way for heterogeneous debates, studies and interpretations. As a result, this diversity could explain the fragmented character of the provided collaboration network. It could impede the convergence of academic contributions, the effective accumulation of knowledge and would strengthen Genus' and Stirling's appeal (2018) for more concrete frameworks.

Although RRI and RI exhibit various research streams that could indicate the emergence of novel research streams worth encouraging through research policy, it is beyond the scope of this paper to reliably identify the most promising ones. Nevertheless, the results suggest a clear distinction between research at the level of the innovation system and research at the actor level. This could be a sensible starting point for the progression of RRI's, RI's or joint research.

2.4.2. Limitations

This study is bound to some limitations that relate to the data collection. While the use of few keywords in an inherently incomplete database may leave out some relevant RRI literature, our use of RPYS partly compensates for this by allowing for a more comprehensive identification of contributions, in any form, inside and outside of the database, and for a more systematic way of collecting relevant references, without having to make subjective choices as to which articles to include. The RPYS is further supported by an additional manual check on anomalies in most recent years (2010-2019) to ensure the inclusion of more recent influential contributions. Undeniably, there may be other contributions that the RRI and RI community rely on and which have proven to be valuable for their progression. In addition, the publication data does not reflect so called 'invisible colleges' (Crane, 1972) and hence only captures codified phenomena. These aspects, however, fall outside of scope of this paper.

The keyword analyses identify the interaction of content between RRI and RI. However, their interchangeable use could decrease the semantic reliability as authors may refer to one but mean the other. Nevertheless, our keyword analyses show a clear upsurge of RRI's usage. The coming years will show if this trend will persist.

2.5. Conclusion

Since the birth of RRI approximately a decade ago, scholars have gazed into the past searching for existing knowledge for contemporary enquiries. While RRI and RI efforts seem to have different origins, RRI more top-down and RI bottom-up, RRI seems to have placed itself in the literature of RI which might have caused some conflation of the concepts. This paper has identified the shared knowledge base of RRI and RI by conducting a systematic quantitative reference analysis. It discussed these in a chronological order and consequently described the evolution of knowledge that now forms RRI's and RI's shared foundation. It underlined the convergence process of knowledge in which distant theories were bridged and developed into increasingly more coherent research trajectories. RRI and RI truly lean on the shoulders of giants with historical roots in (moral) philosophy, economics, and sociology. Influential contributions in the past were concerned with 'if' and 'how' science (and innovation) should be governed. This subsequently gave rise to contributions on reflexive modernity, anticipatory governance, and technology assessment.

The RRI and RI frameworks have been criticised, opposed, endorsed, and transformed which has stimulated their discourse. This study concludes that RRI and RI have matured into an emerging, intertwined, and increasingly cumulative research trajectory that embodies a constellation of interconnected ideas. This is based on its topic interconnectivity, community size, collective productivity, own communication channels, and the presence of its own academic questions, challenges, and research opportunities. These opportunities predominantly relate to the implementation, evaluation, and institutionalisation of RRI and RI frameworks and values in practice at the (innovation) system level and individual actor level. The system level requires answers on how to deal with its politics, systemic barriers, sociocultural (and economic) differences, and actor interactions. It is furthermore concerned with how RRI and RI can be realised in a market-driven environment where there is inequality in actors' power, in the distribution of responsibilities, and a difference in actors' motives, goals, visions, and perspectives. Some of these challenges still apply at the individual actor level, but additionally a great uncertainty needs to be addressed as to whether, and how, individual (industrial) actors will benefit from RRI and RI practices as opposed to solely how society will benefit. For this reason, some scholars are highly sceptical, and plead for more realistic expectations of RRI and RI.

Together, RRI and RI show productivity levels similar to that of Corporate Social Responsibility, Green Innovation and Social Innovation in the years 2009, 2014/2015, and 2008 respectively. Admittedly, RRI and RI are still in their infancy, but support for their research has increased substantially and, hence their coordination requires further consideration. Accordingly, this study indicates that (1) RRI/RI might be collaboratively fragmented, which could be detrimental for the exchange of especially tacit knowledge, (2) only few empirical case studies have been conducted, (3) no practical RRI/RI approach for implementation has gained dominance so far, presumably partly due to the heterogeneous community, and the context-dependent, and broadly-applicable character of RRI/RI. (4) RRI and RI seem to be conceptually interconnected causing conflation. Although, they overlap in some aspects (such as public engagement for, and governance of, emerging technologies) they remain different in others. These four barriers limit RRI's and RI's distinct and joint progression. From a policy perspective, this study therefore appears well-timed, and we suggest that these barriers should be addressed. This could be done by stimulating collaborations and empirical studies in distinct research streams (e.g. at the systemic and actor level). Enabling a collective consensus on the appropriate research ensembles for specific contexts would aid in achieving a more effective knowledge accumulation when considering RRI's and RI's inherent situational approaches. The scientific community should reflect on RRI's and RI's differences and similarities when funding, performing, and steering future research to avoid confusion and provide guidance. In conclusion, RRI and RI form a fast growing research area with abundant research and collaborative opportunities. However, reaching its full potential requires coordination, leadership, clarity, and the further creation of specific theories and concrete frameworks dedicated to either RRI, RI or joint research.

3. Wrestling with Wicked Problems: Approaches from Responsible Innovation

3.1. Introduction

Research and innovation are increasingly expected to help address 'grand societal challenges' such as pandemics, social injustice, and climate change (Foray et al., 2012; Kuhlmann and Rip, 2018; Schot and Steinmueller, 2018). Many of these challenges are *wicked problems* as both their respective problems and required resolutions are complex, uncertain, and contested (Rittel and Webber, 1973). Responsible Innovation (Stilgoe et al., 2013) is a growing academic and policy discourse that various scholars expect could help address these grand societal challenges (e.g., Genus and Stirling, 2018; Jakobsen et al., 2019; Owen et al., 2020; Von Schomberg, 2013).

Responsible Innovation is an umbrella term for proactive, risk-mitigating, and inclusive approaches aimed at enhancing research and innovation's social desirability before outcomes are diffused and ramifications become evident (Burget et al., 2016; Fraaije and Flipse, 2020; Ribeiro et al., 2017). It is associated with a broad range of tools, techniques, instruments, and procedures – hereafter 'approaches' – that allow for a more socially desirable development of challenge-led research and innovation (e.g., Fisher and Mahajan, 2006; Friedman, 1996; Guston and Sarewitz, 2002; Schot et al., 1995; Selin, 2011; Yaghmaei and Van de Poel, 2021).

Many scholars in the public policy literature assume that coping with complexity calls for inclusion, dealing with uncertainty requires anticipation, and addressing contestation necessitates reflexivity (Farrell and Hooker, 2013; Head and Alford, 2015). In Responsible Innovation, complexity, uncertainty, and contestation are each (implicitly) dealt with through inclusive, anticipatory, and reflexive actions. However, in establishing and using Responsible Innovation approaches, most scholars have not explicitly linked these to the wickedness dimensions as set out by Rittel and Webber (1973) that give rise to this complexity, uncertainty, and contestation. This prompts the question whether Responsible Innovation is a fruitful approach to cope with the wickedness of societal challenges (Blok and Lemmens, 2015; Flipse et al., 2015). So far, this has not been systematically studied. As a result, we lack an understanding of which Responsible Innovation approaches are best suited to confront wicked problems (Pesch and Vermaas, 2020).

We address this knowledge gap by conducting a systematic literature review that identifies and appraises the approaches as presented by scholars in the discourse of Responsible Innovation. The analysis first evaluates to what extent approaches of Responsible Innovation conform to the theoretical dimensions set out by its own literature stream. We then follow Vermaas and Pesch (2020) by assessing to what extent these approaches can cope with the ten wickedness dimensions described by Rittel and Webber (1973). We subsequently identify best practices and pinpoint methodological drawbacks that require explicit consideration. These Responsible Innovation approaches may need to be improved through future research, or several complementary approaches can be used jointly. As such, this study provides insight into the meaningfulness of Responsible Innovation approaches for challenge-led research and innovation.

3.2. Theory

In what follows, this section elaborates on the main theoretical dimensions that the literature of Responsible Innovation (Section 3.2.1.) and wicked problems (Section 3.2.2.) respectively set out. Based on these dimensions, this paper proposes methodological conditions that approaches may need to meet to responsibly cope with wicked problems. The conditions are referred to as R.n (Responsible Innovation) and W.n (Wicked Problems), with n indicating the specific condition. Although these conditions form the basis of our data analysis (Section 3.3.), it must be stressed that they do not function as an unequivocal checklist for endorsing particular approaches. The way approaches are practiced can differ from any *a priori* examination. Instead, these conditions offer an entry point for exploring how approaches wrestle with responsibility and wickedness. An overview of these dimensions and conditions is given in Section 3.2.3.

3.2.1. Theoretical dimensions of Responsible Innovation

Responsible Innovation is often defined as "…taking care of the future through collective stewardship of science and innovation in the present" (Stilgoe et al., 2013, p. 1570). Although it can be understood by scrutinizing the purpose, process, and outcome of research and innovation itself, many studies have focused on its ‘upstream’ and ‘midstream’ process (e.g., Fisher and Mahajan, 2006; Rogers-Hayden and

Pidgeon, 2007; Schuurbiers, 2011). This prospective procedural notion partly emerged from an insufficient (normative) understanding of how to govern innovation before path dependencies (David, 1995, 1994), technological lock-ins (Arthur, 1989), and entrenchment set in (Collingridge, 1980). Coping with this so called Collingridge dilemma is suggested to be done through four procedural dimensions, i.e. *anticipation*, *inclusion*, *reflexivity*, and *responsiveness* (Stilgoe et al., 2013). This paper considers these dimensions as normative conditions that research and innovation approaches preferably need to meet.

Approaches should be anticipatory (R.1.) and require actors to consider the question 'what if…' (Ravetz, 1997). It should explore the plausible, possible, and probable, but inherently uncertain, societal risks and benefits of innovations through elements of foresight and imagination (Owen et al., 2013). As such, anticipation aims to articulate desirable impacts (Von Schomberg, 2011).

Inclusion (R.2.) calls for the early exploration of the values, interests, and perspectives of all relevant stakeholders (Bauer et al., 2021). This may be done through forms of communication, consultation, or participation (Rowe and Frewer, 2005). Ultimately, stakeholders will not substitute researchers and innovators, but rather complement them and ground research and innovation firmer into the real world by discarding experts' narrow views and displaying society's plurality of views, knowledge, assumptions, and values (Harremoës et al., 2001).

Responsible Innovation encourages actors to reflect (R.3.) on the alignment of their activities with their societal duties by considering the factors that (implicitly) drive their research and innovation. This reflective capacity is often conceptualized as first-order and second-order reflexivity. First-order reflexivity relates to the "consideration of problem definitions and evaluation of solutions" (Grin and Van De Graaf, 1996, p. 299), which are shaped by a particular set of values (Van de Poel and Zwart, 2010). Second-order reflexivity is concerned with learning about one's value system. This value system is unquestioned in first-order reflexivity (Schuurbiers, 2011).

Approaches should furthermore be adequately responsive (R.4.) in the sense that they proactively redirect research and innovation based on society's values and changing requirements (Stilgoe et al., 2013). This may require changing innovations even if there is no full knowledge. Although actors can respond proactively and reactively (Pellizzoni, 2004), agency might be easier upstream before path-dependencies have been established (Collingridge, 1980; Genus and Stirling, 2018).

3.2.2. Theoretical dimensions of wicked problems

Many societal challenges are wicked; they are complex, uncertain, and contested (Farrell and Hooker, 2013; Head and Alford, 2015). They are *complex* because they are multi-dimensional, multi-scalar, multi-actor, and dynamic (Wanzenböck et al., 2020). This makes it difficult to assign responsibility to particular actors, thus creating a 'problem of many hands' (Thompson, 2005; Van de Poel et al., 2012). Understanding complexity is fundamentally difficult due to insufficient knowledge (Stirling, 2010). They are *uncertain* because there are elements that cannot be known (Hoffmann-Riem and Wynne, 2002). For example, scientists cannot fully understand, and thus foresee, the environmental impacts of climate geoengineering (Pidgeon et al., 2013). Resolvers of wicked problems do therefore not only face the problem of negligence but may also be liable for setting false expectations (Wexler, 2009). Wicked problems are furthermore *contested* due to their plurality of stakeholders that may embody radically different values and worldviews; a resolution that meets one person's preferences might displease others (Pesch and Vermaas, 2020; Schon and Rein, 1994). Addressing societal problems calls for fairness and equity, but stakeholders' interpretations of these values tend to differ considerably (Hart, 1961; Poortinga et al., 2004).

Complexity, uncertainty, and contestation stem from ten dimensions that characterize wicked problems. This subsequently contributes to the fragmentation of problem and resolution framings (Rittel and Webber, 1973). Indeed, these three aspects and the interplay between them determine *in what sense* problems are wicked (Alford and Head, 2017; Wanzenböck et al., 2020). However, the irreducible nature of the ten wickedness dimensions (Head, 2008; Jordan et al., 2014) may obstruct taming or solving them at all without creating new problems (Churchman, 1967; Conklin, 2012; Daviter, 2017). Scholars alternatively speak of 'resolving', 'coping with', or 'addressing' wicked problems (Head and Xiang, 2016; Xiang, 2013). Coping mechanisms aim to unfold "a never-ending discourse with reality, to discover yet more facets, more dimensions of action, more opportunities for improvement" (Dery, 1984, pp. 6–7). This requires a shift towards developmental processes (Daviter, 2017; Head, 2008) and prompts the question which approaches are meaningful in research and innovation. Vermaas and Pesch (2020) argue that approaches should meet conditions that follow from the ten wickedness dimensions set out by Rittel and Webber (1973).

Rittel and Webber (1973) argue that *there is no definitive formulation of a wicked problem* (W.1.). Understanding the problem coincides with any effort of resolving it (Schon and Rein, 1994). Hence, problem formulations emerge parallel to the development of possible resolutions. It follows that problem-resolution configurations are always provisional and contestable (Sweeting, 2018). Approaches should therefore aim to coevolve the framings of problems and resolutions (Wanzenböck et al., 2020).

Wicked problems have no stopping rule (W.2.). They are never solved as there will always be room for improvement. Resolvers do not stop their endeavors because they have resolved the problem. Their pursuit usually ends because of secondary considerations (e.g., no more funding). The innovator may say, "this is the best I can do within the limitations of the project" (Rittel and Webber, 1973, p. 162). Approaches should therefore not aim to find and define optimal resolutions but alternatively seek satisfactory ones.

Solutions to wicked problems are not true or false, but good or bad (W.3.). Although there may be criteria in some scientific domains to determine whether a natural law is unambiguously true or false, this does not apply to resolutions in the context of wicked problems. Social problems are often considered in light of 'soft values' as opposed to 'hard facts' (Funtowicz and Ravetz, 1993; Latour, 2004). Judgements, perceptions, and emotions tend to differ and take on forms such as 'good or bad' and 'better or worse'. Approaches should therefore provide means to determine aspects such as societal goodness and social equity in light of societal pluralism (Pesch and Vermaas, 2020).

There is no immediate and no ultimate test of a solution to a wicked problem (W.4.). Innovations are expected to cause a wide array of unexpected and perhaps undesirable consequences (Hoffmann-Riem and Wynne, 2002; Stirling, 2010). Resolving wicked problems is an inherently uncertain process. As testing is not possible, approaches require forms of foresight while acknowledging the fundamental limits of anticipation (Jasanoff, 2003; Van de Poel, 2016).

Every solution to a wicked problem is a 'one-shot operation'; because there is no opportunity to learn by trial-and-error, every attempt counts significantly (W.5.). As noted by Rittel and Webber (1973), "one cannot build a freeway to see how it works, and then easily correct it after unsatisfactory performance". Many impacts will be irreversible, and ramifications often evoke new wicked problems that pose similar dilemmas. Because every attempt counts, unforeseen problems may arise or problems may change. Approaches should therefore be aware that such cascading effects take place and cause path-dependencies (Farrell and Hooker, 2013).

Wicked problems do not have an enumerable (or an exhaustively describable) set of potential solutions, nor is there a well-described set of permissible operations that may be incorporated into the plan (W.6.). Virtually "anything goes" (Rittel and Webber, 1973, p. 164). Approaches cannot prove that all possible resolutions for wicked problems have been considered. Instead, approaches should encourage its practitioners to establish a non-exhaustive list of possible resolutions.

Every wicked problem is essentially unique (W.7.). Although problems may share commonalities, wicked problems tend to embody distinguishable properties of imperative importance. They are embedded in local contexts, and therefore any resolution has contextual implications (Hannigan and Coffey, 2011). In other words, there are no universal resolutions for these problems. Approaches should develop dedicated resolutions by treating problems as unique.

Every wicked problem can be considered to be a symptom of another problem (W.8.). Although resolving 'lower level' symptoms may seem the most feasible strategy, it will not resolve the 'higher level' cause. It may alternatively worsen the problem because issues manifest themselves without any warning (Churchman, 1967). Approaches should aim to resolve problems at a higher systemic level by searching for a higher cause and exploring its relatedness with other problems.

The existence of a discrepancy representing a wicked problem can be explained in numerous ways. The choice of explanation determines the nature of the problem's resolution (W.9.). No procedure or rule dictates what explanation is the 'correct' one. Innovators need to infer the explanation that they ought most plausible (Lipton, 2004). Because there might be no single best explanation, approaches need to move away from solely focussing on matters of facts, and also include matters of concern (Latour, 2004).

The planner has no right to be wrong (W.10.). As Rittel and Webber (1973) point out, the aim of the innovator should be to improve society's world. They suggest that innovators have the social responsibility to do so, and are liable for the consequences of their actions. Approaches should thus allow for the assignment of an actor's responsibility and liability in the hope that this may incentivize proactive responsiveness (Pellizzoni, 2004).

3.2.3. Conditional framework for Responsible Innovation approaches

While Responsible Innovation approaches are traditionally examined in light of four dimensions to understand how they enhance responsibility (R.1. – R.4.), we follow Vermaas & Pesch (2020) by arguing that approaches should also be evaluated against the ten wickedness dimensions to determine their meaningfulness in addressing societal challenges (W.1. – W.10.). We can evaluate approaches for the development of responsible innovations aimed at dealing with wicked problems, by following the above-mentioned conditions that follow from these 14 dimensions (Table 3-1). The extent to which an approach meets the conditions in the framework may be an indication for how well it is able to cope with the wickedness of societal problems instead of unavailingly resisting them.

Table 3-1: Methodological conditions for responsible innovation and wicked problems

No.	Theoretical dimensions	Methodological conditions
R.1.	Anticipation	Approaches should encourage its practitioners to explore possible future societal risks and benefits of research and innovation.
R.2.	Inclusion	Approaches should encourage its practitioners to explore the values, interests and perspectives of all relevant stakeholders.
R.3.	Reflexivity	Approaches should encourage its practitioners to reflect on their activities' alignment with society's values and expectations.
R.4.	Responsiveness	Approaches should enable its practitioners to be responsive to society's (changing) values and demands.
W.1.	No definite problem formulation	Approaches should encourage its practitioners to coevolve the framings of problems and resolutions.
W.2.	No stopping rule	Approaches should encourage its practitioners not to find and define optimal resolutions but alternatively seek satisfactory ones.
W.3.	Solutions are not true or false	Approaches should encourage its practitioners to determine aspects such as societal goodness and social equity in light of societal pluralism.
W.4.	No tests for solutions	Approaches should enable its practitioners with forms of foresight while acknowledging the fundamental limits of anticipation.
W.5.	Solutions are path-dependent one-shot operations	Approaches should encourage its practitioners to be aware that cascading effects take place and cause path-dependencies.
W.6.	No exhaustive set of solutions	Approaches should encourage its practitioners to establish a non-exhaustive list of possible resolutions.
W.7.	Problems are unique	Approaches should enable its practitioners to develop dedicated resolutions by treating problems as unique.
W.8.	Problems are symptoms of other problems	Approaches should encourage its practitioners to resolve problems at a higher systemic level by searching for a higher cause, and exploring its relatedness with other problems.
W.9.	Dependence of solution on explanation of the problem	Approaches need to move away from solely focussing on matters of facts, and also include matters of concern.
W.10.	No right to be wrong	Approaches should allow for the assignment of its practitioners' responsibility and liability.

3.3. Method

This study aims to identify Responsible Innovation approaches discussed in the literature and assesses their usefulness in confronting wicked societal challenges through research and innovation. Approaches were identified by means of a systematic literature review as this method offers a more comprehensive, reproducible, and less biased analysis than other review methods (Tranfield et al., 2003). The systematic data collection and analysis (Figure 3-1) used metadata from the ISI Web of Science (WoS) database – one of the world's largest publication database. All author keywords (plus®), titles, and abstract words of English articles, reviews, and book chapters published between 2011-2021 containing 'responsible innovation' or 'responsible research and innovation' in combination with the word 'approach' or any synonym such as 'method', 'tool', 'instrument', 'mechanism', 'technique', 'procedure', 'decision-making' and 'assessment' were retrieved. Synonyms were included to enhance the review's validity. The use of the 'research area' filter of WoS was avoided as Responsible Innovation is an inherently interdisciplinary field. Although 'Responsible Innovation' and 'Responsible Research and Innovation' are conceptually different, this study uses both search terms as both domains overlap and are frequently used interchangeably (Wiarda et al., 2021). In addition, while the notion of responsibility in research and innovation has been around for decades (Owen and Pansera, 2019), the respective time period is chosen as the concept that scholars tend to refer to as Responsible Innovation predominantly emerged after two influential contributions, i.e., Von Schomberg (2011) and Stilgoe et al. (2013). These events have, in combination with the European Commission's policy discourse, contributed to a tremendous growth of literature on Responsible Innovation (e.g., Loureiro and Conceição, 2019; Ribeiro et al., 2017; Timmermans, 2017). This search strategy resulted in a sample of 676 contributions.

This study follows Stilgoe et al.'s (2013) terminology by defining approaches as any mechanism that may articulate the four responsibility dimensions in practice, i.e., anticipation, inclusion, reflexivity, or responsiveness. All abstracts were examined for relevancy to exclude contributions that do not discuss Responsible Innovation approaches in accordance with this definition, leaving 343 contributions. Subsequently, these remaining contributions were fully scanned to exclude articles that do not discuss any anticipatory, inclusive, reflexive, or responsive approaches in-depth, leaving 329 records. Single approaches may go by multiple names (e.g., public participation and citizen participation), or approaches may belong to a coherent group of approaches (e.g., constructive technology assessment and real-time technology assessment). Approaches were therefore clustered based on their methodological coherency to enhance the comprehensibility of this study's assessment. While approaches may partly overlap, for analytical purposes we have clustered them in distinct categories. In addition, records can mention a generic approach (e.g. open innovation) without specifying the exact type of approach (e.g. co-design). To mitigate selection bias, we include both generic and specific approaches in our analysis. This resulted in 42 approach clusters (Figures 3-1 & 3-2). Appendix B contains a brief description of all identified approaches. Although some approaches can be used in different contexts, many relate to a particular scale of implementation (Doorn et al., 2013). Approaches were therefore further categorized in accordance with Steen's (2021) classification of implementation scales (Figure 3-2): at the individual/group/project level (micro), the organizational level (meso), or the national/systemic/sectoral level (macro). This classification is based on how the majority of records position approaches. It allows for a more meaningful comparison of approachess, and provides more insight on the focus of Responsible Innovation.

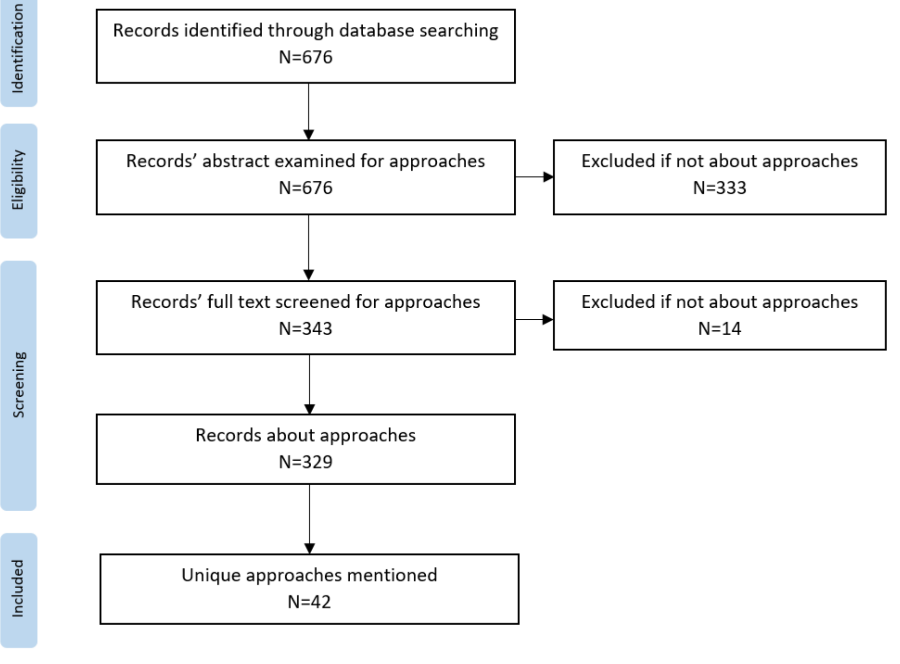

Figure 3-1: Flow diagram of the systematic identification of Responsible Innovation approaches (based on Moher et al. (2009))

We follow Vermaas and Pesch (2020) by evaluating each approach *a priori* based on its ability to cope with each wickedness dimension introduced by Rittel and Webber (1973) and on its ability to meet the mentioned responsibility dimensions (see Table 3-1 for all conditions). Conditions related to these dimensions function as coding rules for the assessment. It is important to stress that our assessment is an analytical reconstruction that offers an initial understanding of approaches. We therefore echo the limitation as pointed out by Vermaas and Pesch (2020) that the approaches' empirical manifestations may unfold differently than our conceptual inquiry. In assessing the approaches, the following scores were assigned: meets condition (green); meets condition to a certain extent/depends on context (yellow); does not meet condition (red); unclear (grey; figure 3-3). A binary assessment was avoided to yield more nuanced results in light of ambiguity. Approaches were evaluated based on the descriptions of the approach in the respective records. For example, Muiderman et al. (2020) state that the approach *anticipatory governance* seeks to "question assumptions about what futures are possible … under conditions of complexity and scientific uncertainty" (p. 2). This suggests that *anticipatory governance* meets condition W.4. as it embodies forms of foresight while recognizing uncertainty. The assessment was first done per individual approach after which the different approaches' assessments were compared to avoid inconsistency. The assessment was performed by the first author and subsequently reviewed by the co-authors to enhance the reliability of the study. Any intercoder disagreements were discussed and resolved.

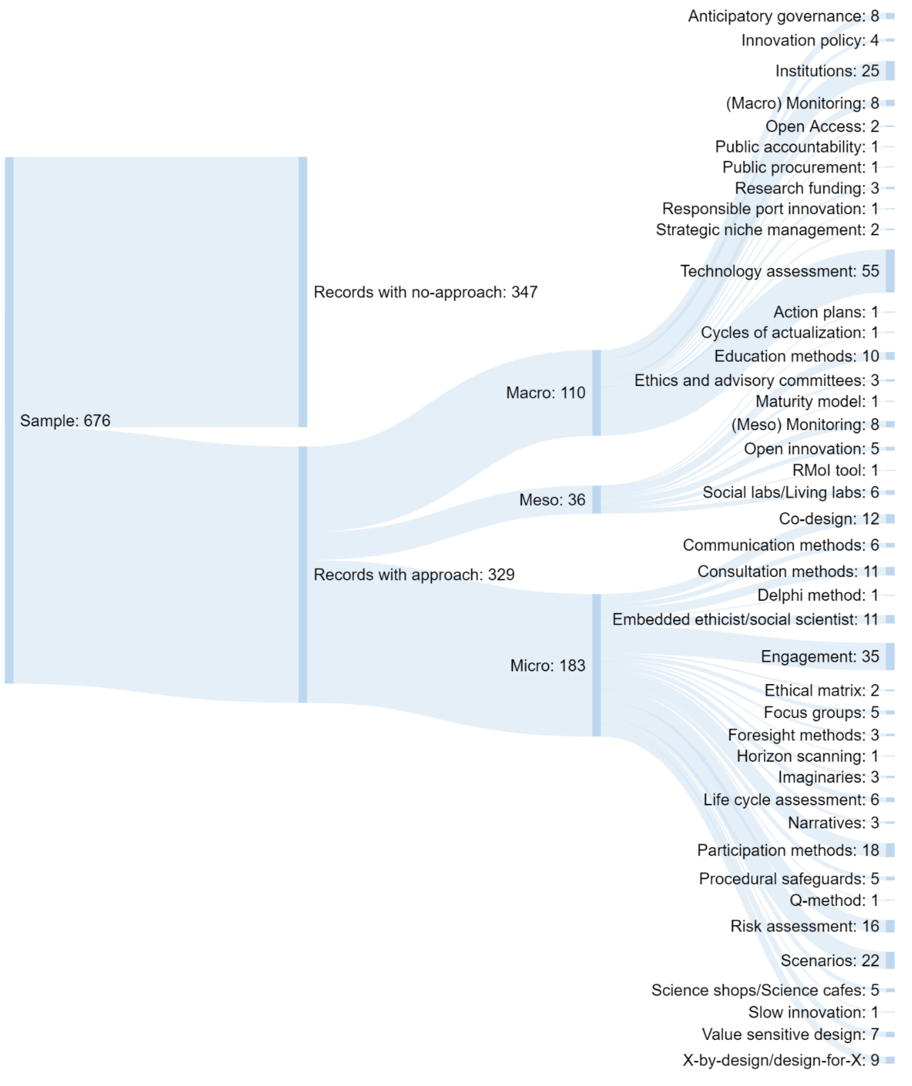

Figure 3-2: The identification process of Responsible Innovation approaches

3.4. Results

This section briefly discusses the most frequently mentioned Responsible Innovation approaches, followed by an assessment of the approaches in terms of the 14 (four Responsible Innovation and ten wickedness) conditions.

3.4.1. Responsible Innovation approaches

The results suggest that Responsible Innovation predominantly focuses on the individual, group, and project (micro) scale of implementation (183 records; 22 approaches). This is followed by a large share of records on the macroscale (110 records; 11 approaches), while the organisational (meso) scale of implementation has received relatively little attention (36 records; 9 approaches). Although the macro and mesoscale include a comparable number of approaches, the discussion of macroscale approaches is more extensive when considering the number of records per scale: 110 for the macroscale (on average 10 per approach) versus 36 for mesoscale (on average 4 per approach).

Technology assessment (TA; N = 55) appears to be discussed most. It can be described as a tool for *anticipatory governance* (N = 8; Muiderman et al., 2020) that allows its practitioners to identify, and assess possible impacts of technologies in an early developmental stage. A range of TAs have emerged, e.g., constructive TA (Rip and van Lente, 2013), health TA (Miller et al., 2020), ethical(-constructive) TA (Kiran et al., 2015), and participatory TA (Kaplan et al., 2021). Scholars also draw on *scenarios* (N = 22; Betten et al., 2018), *imaginaries* (N = 3; Roßmann, 2021), and other *foresight methods* (N = 3; Barre, 2014) as popular anticipatory tools to imagine probable and possible futures. A frequently mentioned benefit of these approaches is that they go beyond *risk assessment* (N = 16) by also including non-quantifiable plausible (and sometimes even fictional) socio-ethical impacts (Miller, 2015).

Responsible Innovation has additionally dedicated efforts to *engagement* (N = 35; Bauer et al., 2021; Jellema and Mulder, 2016; te Kulve and Rip, 2011). Although many records consider engagement in the general sense, several contributions have focused on more specific approaches such as *communication methods* (N = 6; Gertrudix et al., 2021), *consultation methods* (N = 11; Capurro et al., 2015; Pidgeon et al., 2013), and *participation methods* (Fitzgerald et al., 2016; N = 18; Mouter et al., 2021), which can all be seen as specific types of engagement methods. Specific examples that fall under these approaches are *co-design* (N = 12; Macdonald et al., 2021; Macken-Walsh, 2019), *open innovation* (N = 5; Long and Blok, 2018), and *focus groups* (N = 5; Lynch et al., 2017).

Furthermore, a large proportion of records focus on hard and soft *institutions* (N = 25) to encourage or enforce actors to engage in the 'right' practices. Although a few scholars focus on regulations as the legal framework in which innovators work (e.g., De Wert et al., 2018; Meghani and Kuzma, 2018), most records refer to other (soft) institutions such as guidelines (Boenink, 2018; Wilford, 2018), codes of conducts (Grunwald, 2014) and standards (Garfinkel, 2021; Wickson and Forsberg, 2015).

Responsible Innovation scholars also mention approaches such as the *embedded ethicist/social scientist* (Lukovics et al., 2017; N = 11; Schuurbiers, 2011), *education methods* (N = 10; Wickson et al., 2015), and R(R)I *monitoring* for either the mesoscale (N = 8; Yaghmaei, 2018) and macroscale of implementation (N = 8; Mejlgaard et al., 2018). Other frequently mentioned approaches include *value sensitive design* (N = 7; Dignum et al., 2016) *and X-by-design/design-for-X* (N = 9). With *value sensitive design* referring to the design for a plurality of (sometimes conflicting) values, while *X-by-design/design-for-X* prioritising a particular value, e.g., safety in the case of safe-by-design (van Gelder et al., 2021).

Less frequently mentioned approaches are: *social labs/living labs* (N = 6; Timmermans et al., 2020) for socio-technical experiments; *science shops/science cafes* (Balázs et al., 2020; N = 5; Urias et al., 2020) as spaces for interactions with society; *procedural safeguards* (N = 5; Boers et al., 2018) like informed consent; and *life cycle assessments* (N = 6; Wender et al., 2014) as the analysis of a product's environmental impact – from design to disposal.

Approaches that are mentioned least include *horizon scanning* (N = 1; Fleming et al., 2021), *public procurement* (N = 1; Uyarra et al., 2019), *cycles of actualization* (N = 1; Batayeh et al., 2018), *action plans* (N = 1; Colizzi et al., 2019), *slow innovation* (N = 1; Steen, 2021), *Delphi method* (N = 1; Brier et al., 2020), *q-method* (N = 1; Schuijff et al., 2021), *responsible port innovation* (N = 1; Ravesteijn et al., 2015), *Responsible Management of Innovation tool* (RMoI tool; N = 1; Long et al., 2020), and the *maturity model* (N = 1; Stahl et al., 2017).

3.4.2. Approach assessment

As discussed, all 42 approaches have been assessed in light of the methodological conditions listed in Section 3.2.3. The results (Figure 3-3) suggest that Responsible Innovation tends to meet its own methodological conditions, and has the potential to cope well with the wickedness conditions needed for societal challenges. However, this is not unequivocal as conditions are frequently met only to a certain extent or only in specific contexts. The aim for which the approach is used and how it is used are decisive in this regard.

By specifically considering the approaches' scores (i.e., the sum of green and yellow; Figure 3-3), we gain a better understanding of their coping ability. Macroscale approaches that can potentially cope (to a certain extent/in certain contexts) with all wickedness dimensions are *anticipatory governance*, *innovation policy*, *public accountability*, *research funding*, *strategic niche management*, and *technology assessment*. Mesoscale approaches that do so are scarce. Organizations may draw on a*ction plans* as formulated by Colizzi et al. (2019) as a comprehensive approach to attain the ideals of Responsible Innovation while potentially meeting the wickedness conditions. A great number of scholars have also considered institutionalizing Responsible Innovation through pre-employment education. These respective *education methods* greatly differ, which makes this approach highly contextual. Organizations can furthermore draw on the *RMoI tool* (Long et al., 2020) as a relatively comprehensive approach to responsibly develop innovations to address wicked problems. Promising microscale approaches include *engagement* and *participation methods* such as *co-design*, *open innovation*, *ethical matrix*, and *science shops/science cafes*. In addition, a broad range of other potentially fruitful anticipatory, reflexive and/or responsive approaches include the *embedded ethicist/social scientist*, *slow innovation*, *foresight methods*, *narratives*, *scenarios*, *value sensitive design*, and *x-by-design/design-by-x*.

Focussing on the different conditions, we see that the wickedness conditions that are (to a certain extent/in certain contexts) met most by the different Responsible Innovation approaches are: treating problems as unique (W.7.; score = 40)[9]; including matters of concern next to matters of fact (W.9.; score = 39); seeking satisfactory results instead of optimal ones (W.2.; score = 38); determining aspects of societal goodness and social equity in view of plurality (W.3.; score = 38); and encouraging practitioners to be aware of cascading effects that take place and cause path-dependencies (W.5.; score = 38).

The conditions that are met least by Responsible Innovation are: coevolving problem-resolution framing (W.1.; score = 31); providing foresight, or being explicitly aware of its limits (W.4.; score = 32); understanding wicked problems as symptoms of other, often interrelated, problems (W.8.; score = 35); and allowing for the assignment of its practitioners' responsibility and liability (W.10.; score = 35). In what follows, Section 3.5. clarifies these results and discusses possible implications.

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9 Based on the total green and yellow scores, suggesting that approaches (could) meet conditions.

Scale	Approach	No. records	R.1.	R.2.	R.3.	R.4.	W.1.	W.2.	W.3.	W.4.	W.5.	W.6.	W.7.	W.8.	W.9.	W.10.	Red	Yellow	Green	Grey	Total (green + yellow)
Macro	Anticipatory governance	8															0	5	9	0	14
	Innovation policy	4															0	13	1	0	14
	Institutions	25															4	6	4	0	10
	(Macro) Monitoring	8															7	5	2	0	7
	Open Access	2															6	5	3	0	8
	Public accountability	1															0	4	10	0	14
	Public procurement	1															1	9	4	0	13
	Research funding	3															0	6	8	0	14
	Responsible port innovation	1															1	2	11	0	13
	Strategic niche management	2															0	6	8	0	14
	Technology assessment	55															0	4	10	0	14
Meso	Action plans	1															0	1	12	1	13
	Cycles of actualization	1															2	4	6	2	10
	Education methods	10															0	12	2	0	14
	Ethics and advisory committees	3															2	2	10	0	12
	Maturity Model	1															4	5	5	0	10
	(Meso) Monitoring	8															6	4	4	0	8
	RMoI Tool	1															1	4	9	0	13
	Social labs/Living labs	6															3	3	8	0	11
Micro	Co-design	12															0	5	9	0	14
	Communication methods	6															6	6	2	0	8
	Consultation methods	11															1	4	9	0	13
	Delphi method	1															1	4	9	0	13
	Embedded ethicist/social scientist	11															0	2	12	0	14
	Engagement	35															0	11	3	0	14
	Ethical Matrix	2															0	6	8	0	14
	Focus group	5															1	5	8	0	13
	Foresight methods	3															0	9	5	0	14
	Horizon scanning	1															1	7	6	0	13
	Imaginaries	3															1	5	8	0	13
	Life cycle assessment	6															4	5	5	0	10
	Narratives	3															0	8	6	0	14
	Open Innovation	5															0	7	7	0	14
	Participation methods	18															0	9	5	0	14
	Procedural safeguard	5															3	5	5	1	10
	Q-method	1															1	6	7	0	13
	Risk assessment and management	16															1	9	4	0	13
	Scenarios	22															0	7	7	0	14
	Science shops/Science cafes	5															0	4	10	0	14
	Slow innovation	1															0	5	8	1	13
	Value sensitive design	7															0	4	10	0	14
	X-by-design/design-for-X	9															0	8	6	0	14
Total	Red		1	1	0	1	11	4	4	8	4	4	2	7	3	7					
	Yellow		21	14	12	14	19	22	18	26	20	14	7	24	7	23					
	Green		19	27	30	27	12	16	20	6	18	22	33	11	32	12					
	Grey		1	0	0	0	0	0	0	2	0	2	0	0	0	0					
	Total (green + yellow)		40	41	42	41	31	38	38	32	38	36	40	35	39	35					

Figure 3-3: Approach assessment matrix. Green = meets condition, yellow = meets condition to certain extent/depends on context, red = does not meet condition, grey = unclear.

3.5. Discussion

In the previous section, we explored whether Responsible Innovation approaches (Appendix B) can cope with the wickedness dimensions of societal challenges. We would like to stress that the considered conditions should not be seen as an unequivocal checklist. Practices can differ from any *a priori* examination, and our proposed methodological requirements are likely not the only way to wrestle with wickedness. Instead, these conditions provide an entry point for exploring how approaches that are often considered responsible may confront wicked problems head-on.

Our results suggest that several approaches have the potential to meet these conditions. Some macroscale approaches that presumably deal well with wicked problems include *anticipatory governance*, *technology assessment*, and *public accountability*. They share the trait that they handle problems as unique (W.7.), are sensitive to decisions' cascading effects and path-dependencies (W.5.), recognize social pluralism (W.3.), and take into consideration matters of concerns next to matters of facts (W.9.). For instance, Kaplan et al. (2021) describe that their *technology assessment* aimed to "determine how to frame the policy problem from a diversity of perspectives" (p. 4), satisfying condition W.3. By reason that *education methods* are versatile, they can essentially be tailored to meet all conditions. Yet, more structured approaches such as the *RMoI tool* and *action plans* likewise appear useful, for instance, because they (implicitly) acknowledge cascading effects and path dependencies (W.1.) and treat problems as unique (W.7.). *Action plans* as described by Colizzi et al. (2019), for example, conduct a context analysis to understand the unique conditions that the approach is performed in. Responsible Innovation draws on multiple microscale approaches that seem meaningful in the context of wicked problems. These include among others *co-design*, the e*mbedded ethicist/social scientist*, *scenarios*, *science shops/science cafes*, *X-by-design/design-for-X, and value sensitive design*. As an illustration for the latter, Dignum et al. (2016) argue that "while virtually everybody would endorse the notion that we need a just society, there are various opinions about what justice exactly entails". This exemplifies how *value sensitive design* aims to seek societal goodness in light of societal pluralism (W.3.)

While this is promising, practitioners should always be attentive to whether approaches align with a societal problem's nature. This is crucial for at least two reasons. First, approaches generally differ in their objectives, implementation scale, and responsibility definitions. Safe-by-design, for instance, has a focus on safety while it may neglect other important values (van Gelder et al., 2021). Second, not all wicked problems are fully wicked or tame, as problems may be characterized by only a selection of wicked dimensions (Alford and Head, 2017; Wanzenböck et al., 2020). Therefore, approaches that do not meet all conditions may still be useful in specific contexts.

Our results indicate that most records relate to *technology assessment*, *engagement*, *institutions*, and *scenarios*. When considering the scale of implementation, Responsible Innovation has primarily focused on practices for the micro and macro scale context. The organizational context seems to be understudied and requires new ways of conducting research and innovation responsibly. This is important as both responsibility and transformative change require interventions on, and synergy between, all levels of innovation systems (Timmermans et al., 2020).

In general, Responsible Innovation's strength in confronting wicked problems lies in treating problems as unique (W.7.) and taking into account public concerns next to scientific facts (W.9.). Moreover, it does well in seeking satisfactory outcomes instead of optimal ones (W.2.) and identifying aspects of societal goodness and social equity in light of societal pluralism (W.3.). Another strength appears to lay in encouraging practitioners to be aware of cascading effects that take place and cause path-dependencies (W.5.). While not the focus of our study, we speculate that these strengths partly emerge from the prevalent mode in which Responsible Innovation operates – a procedural focus that aims to identify and bridge the context-specific values and worldviews of stakeholders.

Our results also hint towards possible methodological drawbacks by indicating which conditions are met least. These could be addressed through future research. First, Responsible Innovation seems to struggle to coevolve problem and resolution framings as it tends to focus on either the problem or the resolution (W.1.). A narrow focus on only one is expected to fail as long as there is divergence in how the other is framed (Wanzenböck et al., 2020). To cope with this, high levels of reflexivity are needed for provisional definitions of problems and resolutions to continuously interact through feedback loops (Weber and Rohracher, 2012). Exemplary approaches that do so are the *embedded ethicist/social scientist* (e.g., Socio-Technical Integration Research; Fisher, 2007) and (real-time) *technology assessment* (Guston and Sarewitz, 2002).

Second, we find a lack of foresight in a large proportion of approaches, and/or the explicit awareness of uncertainty that comes with resolving wicked problems (W.4.). While innovations generally cause a wide array of unexpected consequences (Hoffmann-Riem and Wynne, 2002; Stirling, 2010), this is especially the case for wicked problems. This is due to the difficulties of testing resolutions (Rittel and

Webber, 1973) and to the radical uncertainty associated with the constantly changing problems-resolution space (Blok and Lemmens, 2015). Although foresight is crucial, this also calls for humility regarding the limits of anticipation (Jasanoff, 2007). Wexler accordingly argues that practitioners should not only be held accountable for negligence, but also for setting unreasonably false expectations (Wexler, 2009). Therefore, it may be more appropriate to aim for a better understanding of the implicit worldviews and concerns embedded in the socio-technical *imaginaries* of practitioners, especially how these differ from other stakeholder groups (Jasanoff and Kim, 2015). As such, reflexive *imaginaries* may derive humility from recognizing the differences and degree of divergence of these constantly coevolving ideas about (un)desirable futures based on provisional problems in the present.

Third, future research needs to address how approaches can comprehend wicked problems as symptoms of other (interrelated) problems by using system perspectives or higher-cause analyses (W.8.). While higher problem framings are more general and harder to solve, easier lower-level problems may only cure symptoms that consequently merely 'hide' higher-level problems (Churchman, 1967; Rittel and Webber, 1973). In light of the Collingridge dilemma, Responsible Innovation tends to examine 'responsiveness' in relation to the *timing* of interventions (Genus and Stirling, 2018; Pellizzoni, 2004; Stilgoe et al., 2013). However, wicked problems additionally demand considerations of the *systemic level* of interventions. Approaches need to balance between moving problems up by asking "why…?" and remaining low enough to retain adequate agency and be sensitive to local contexts. It thus requires actors to carefully consider on what level and scale they should evolve problem-solution spaces. Nevertheless, we lack an understanding of how to deal with this, what we call, multi-scalarity dilemma.

Fourth, while Responsible Innovation has dedicated significant efforts to understanding concepts such as responsibility and accountability, determining these aspects in relation to its own practices remains challenging (W.10.). This frequently stems from their complex deliberative and collective nature, giving rise to 'problems of many hands' (Doorn and Van de Poel, 2012). Indeed, scholars advocate collective action and collective responsibility (e.g., Stilgoe et al., 2013; Von Schomberg, 2011), but this complicates assigning responsibility and therefore accountability while practitioners have "no right to be wrong" (Rittel and Webber, 1973, p. 166). This is problematic as responsible decision-making preferably requires consensus on the right course of action, and it is precisely this consensus that is difficult to reach in the context of wicked problems (Blok and Lemmens, 2015; Pesch and Vermaas, 2020). Therefore, some scholars question whether Responsible Innovation should always aim for agreement (Owen et al., 2021b). A *constructive approach* aligns with this view by building on conflicts instead of resolving them, and by striving for a better understanding of divergent problem-solution spaces (Cuppen, 2012). Transparency may help foster such mutual understanding and has gained increasingly more attention as a complementary dimension to the four responsibility dimensions discussed in this paper (Fraaije and Flipse, 2020). Nevertheless, mutual understanding and transparency are likely inadequate elements for addressing wicked problems as conflicts tend to be rooted in fundamentally incompatible principles (Schon and Rein, 1994). Not acting is neither an option as the resulting standstill can also be seen as favouring one problem definition over some other. It has therefore been proposed to develop *agonistic approaches* that demand an ethical response despite contestation (Popa et al., 2021; Scott, 2021). This would require difficult decisions to be made without disregarding other perspectives as irrational (Mouffe, 2000). While agonistic deliberative theory is not new, its application to the context of technology and innovation is of recent date. How room for contestation can be safeguarded in this context is an open question.

The four methodological shortcomings identified can be addressed through the creation, or improvement, of approaches, or they could be combined to compensate for each other's drawbacks. *Action plans* as described by Colizzi et al (2019) exemplify how combining approaches can lead to a more comprehensive and responsible approach. As stressed before, the exact combination of approaches depends on the wicked problem and goal of the practitioner as approaches have very different aims and definitions of responsibility.

Indeed, creating, improving, or combining approaches for responsible and challenge-led research and innovation is not without challenges. Nevertheless, this paper followed the normative imperative that wicked problems must be addressed regardless of the difficulty (Peters, 2017). Some scholars go even further by stating that scholars have the obligation to improve and develop approaches (Martin and Dunne, 2006; Wexler, 2009). While the current paper has considered several underlying dimensions of wicked problems, it would be insightful to better understand how Responsible Innovation approaches contribute to alternative strategies – other than 'coping' – such as 'taming' or even attempts to 'solving' wicked problems (Daviter, 2017). In addition, it seems important to better understand Responsible Innovation's relationship with other societal problem typologies (Hoppe, 2011; e.g., Lazarus, 2009; May et al., 2013) and wickedness dimensions (e.g., Head and Alford, 2015; Ooms and

Piepenbrink, 2021). For example, 'super wicked problems' form an important typology that offers additional dimensions: "time is running out [1]; those who cause the problem also seek to provide a solution [2]; the central authority needed to address them is weak or non-existent [3]; and irrational discounting occurs that pushes responses into the future [4]" (Levin et al., 2012, p. 124). Responsible Innovation certainly takes time (Steen, 2021), but this is exactly what we lack when addressing super wicked problems. Although quick, but provisional, collective responses that preserve future agency may buy time for more reflexive, anticipatory, and still more inclusive considerations, we currently lack the insights regarding the meaningfulness of such an approach to super wicked problems'.

Lastly, it is important to stress the limitations that are associated with this study. First, it takes stock of approaches that are explicitly positioned in the discourse of Responsible Innovation. Needless to say, there are other academic fields that put forth anticipatory, inclusive, reflexive, and responsive approaches that could address wicked problems. These approaches and academic fields, however, lay beyond the scope of this research and were therefore not included. Second, our exploratory results are based on the approaches' conceptual reconstruction and are therefore not supported by empirical data. Third, some approaches in our analysis are context dependent or not fully defined. As a result, this obscures outcomes. We have accounted for this, by making this explicit in the results (Figure 3-3).

3.6. Concluding Remarks

This paper examined the extent to which Responsible Innovation is able to meaningfully respond to wicked problems. It has done so by evaluating its approaches against methodological conditions that are based on some underlying dimensions of these problems. Several approaches from Responsible Innovation appear to meet these conditions to a certain extent and/or under specific circumstances. However, our analysis suggests that the methodological drawbacks of Responsible Innovation seem to lay in inadequately coevolving problem-resolution framings (1); occasionally lacking foresight and/or the explicit awareness of its limitations (2); overlooking the notion that wicked problems are symptoms of other (interrelated) problems (3); and frequently struggling to determine aspects such as responsibility and accountability in relation to its own practices due to their collective and deliberative nature (4). Overcoming these methodological drawbacks requires us to improve, combine, or reimagine approaches that have a greater shot at addressing challenges responsibly.

This appears particularly urgent for the organizational context which currently lacks a rich pool of capable approaches. Although few studies have considered the link between Responsible Innovation and wicked problems, we would also like to argue for more research on Responsible Innovation's relationship with other problem typologies and wickedness dimensions next to the ten wickedness dimensions set out by Rittel and Webber (1973). It must be stressed that wicked problems are wicked for a reason. We therefore echo that methodological discussions should discourage naïve or false expectations about how wickedness can be addressed (Wexler, 2009). Our contribution is hence cautious, but it contributes by suggesting new ways forward for Responsible Innovation to address the grand societal challenges of our time.

4. Responsible Innovation and De Jure Standardisation: An In-Depth Exploration of Moral Motives, Barriers, and Facilitators[10]

4.1. Introduction

Responsible innovation (RI) has become a burgeoning research field in the past decades (Burget et al., 2016; Owen et al., 2012). It is often described as an inclusive and risk-mitigating approach to research and innovation and stems from long traditions of science and technology studies and ethics of technology (Owen and Pansera, 2019; Wiarda et al., 2021). Various scholars have emphasised the role of standards in implementing RI (e.g. Stilgoe et al., 2013; Wickson and Forsberg, 2015).

Standards have substantial technical and socio-economic impacts (Cowan, 1992) and affect many aspects of life (Timmermans and Epstein, 2010). Given this impact and ubiquity, it is important that standards are well-aligned with society's values (Friedman, 1996; Ligtvoet et al., 2015; Wickson and Forsberg, 2015). This is particularly important in light of the voluntary nature of many standards as their use largely depends on societal support (Brunsson et al., 2012).

A large proportion of standards are developed through a process called *de jure* standardisation (Narayanan and Chen, 2012). In this process, stakeholders cooperatively create standards in committees that are only diffused when consensus is established (Wiegmann et al., 2017). Standard developing organisations (SDOs) facilitate this process (Simcoe, 2012).

Due to standards' normative nature, standardisation is also increasingly seen as a means to proactively insert ethics in innovation processes (Busch, 2012; Thompson, 2021). While this potential of standardisation has been recognized in the standardisation and the RI literature, insight into how ethics-inspired frameworks fit

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existing standardisation practices is currently lacking (Inigo et al., 2021; Van De Kaa, 2013; Wickson and Forsberg, 2015).

Within in the field of RI, there is a consensus that responsible processes require at least forms of *anticipation*, *inclusion*, *reflexivity*, and *responsiveness* (Fraaije and Flipse, 2020; Stilgoe et al., 2013). This focus leaves room for a contextualised substantiation of RI. Actors can include diverse values and worldviews that form preconditions to understand what risks and uncertainties are ethically acceptable, challenge (implicit) drivers of researchers and innovators, and align innovations with society's expectations.

However, it remains unclear how these four procedural dimensions are institutionalised in the process of *de jure* standardisation and what factors motivate, obstruct, or facilitate the uptake of these dimensions in this process.

This study addresses these two knowledge gaps by examining the extent to which the four dimensions of RI are institutionalised in the process of *de jure* standardisation. It subsequently explores what factors may affect their institutionalisation. In the remainder of this paper, we use the term 'responsible standardisation' to refer to standardisation processes that are shaped according to the four procedural RI dimensions.

We consider the Royal Dutch Normalisation Institute as our case study. By extension, this study derives a practical understanding of responsible standardisation and aims to lay the groundwork for future research on this topic.

This paper first positions the RI literature in the context of standardisation. It then explains the research design and proceeds with presenting and discussing the results.

4.2. Four Dimensions of Responsible Innovation

Research on RI in the process of *de jure* standardisation is scarce, and an understanding of the concept of responsible standardisation appears absent. While this is the case, there is a general consensus that responsible processes in innovation should at least embody forms of *anticipation*, *inclusion*, *reflexivity* and *responsiveness* (AIRR framework; Burget et al., 2016; Fraaije and Flipse, 2020; Owen et al., 2021a; Stilgoe et al., 2013), and processes that do so are expected to lead to more responsible outcomes (Fraaije and Flipse, 2020), i.e. responsible standards (Wickson and Forsberg, 2015).

First, anticipation urges actors to raise the question 'what if…?' (Ravetz, 1997) and to imagine what possible risks and uncertainties are present. Second, inclusion requires broad and early engagement with stakeholders to yield diverse insights (Bauer et al., 2021; Chesbrough, 2003). Third, reflexivity requires actors to challenge their drivers and align their work with their moral responsibility (Schuurbiers, 2011; Van de Poel and Zwart, 2010). Fourth, responsiveness calls for the capability to change the shape and direction of innovations in light of anticipatory, inclusive, and reflexive insights (Pellizzoni, 2004; Stilgoe et al., 2013).

The procedural nature of these four dimensions additionally helps cope with the so called Collingridge dilemma (Collingridge, 1980), i.e., the insufficiency of knowledge on how the shape innovations before path dependencies (David, 1995, 1994) and technological lock-ins emerge (Arthur, 1989). The AIRR framework consequently has the potential to support actors in proactively aligning research and innovation with early values and worldviews before this becomes problematic (Stilgoe et al., 2013). As a result, an enhanced ethical acceptability is suggested to lead to more legitimate and desirable outcomes that potentially yield more support and market acceptance (Fraaije and Flipse, 2020).

By departing from the normative view that these four procedural RI dimensions are necessary for responsible standardisation, this study attempts to bridge the literature of RI with standardisation, to provide a theoretical lens for understanding responsible *de jure* standardisation processes. The theory presented below is thus an aggregation of standardisation research that resonates with the four dimensions of RI.

4.2.1. Anticipation and standardisation

Anticipation requires actors to embrace the uncertain outcomes of standardisation. Imagination and systemic analyses can identify risks and benefits that innovations might bring about (Guston and Sarewitz, 2002; Stilgoe et al., 2013). *De jure* standardisation is an anticipatory process (Fomin, 2011) which predominantly occurs in the earliest phases of a technological development (David and Shurmer, 1996; Jakobs, 2006; Wiegmann et al., 2017). Uncertainties of future technologies, markets, and user values dominate this stage (David and Shurmer, 1996). Hence, foreseeing standardisation needs and outcomes is challenging (Featherston et al., 2016; Simcoe, 2005). Anticipatory standards are (1) characterised by their intention to guide future technological compatibility or interoperability; (2) created in (inter)national regulatory contexts that facilitate coordination between firms; and (3) openly accessible to all parties (Lyytinen and King, 2006). Their negotiations are particularly concerned with technical needs (Takahashi and Tojo, 1993). However, little research has evaluated whether anticipatory standardisation activities go beyond the purely technical and economic, and analyse and explore the broader societal impacts of standards.

4.2.2. Inclusion and standardisation

Inclusion refers to involving stakeholders throughout the development process to acquire diverse input. Inclusion is a core element of RI (Owen et al., 2021a; Stilgoe et al., 2013) and collective action in standardisation (Hargrave and Van de Ven, 2006; Van den Ende et al., 2012). Stakeholder diversity provides for diverse information (De Vries, 1999; Markus et al., 2006). It is broadly acknowledged that this forms a requisite for novel knowledge (Allen, 1977; Arthur, 2007). As such, inclusion can shape and improve a standard's content (Egyedi, 1996; Schmidt et al., 1998), and may lead to better and more ethical decision making (Nathan, 2015; Stahl, 2013). It does so by internalising society's needs and values in standards (Evans et al., 1993; Friedman, 1996; Lundval, 1995; Markus et al., 2006). Inclusion can also increase the legitimacy of standardisation processes and outcomes (Forsberg, 2012; Fransen and Kolk, 2007; Lundval, 1995; Scharpf, 1999). Standard proposals that survive stakeholders' scrutiny are expected to enjoy extensive support (Fischhoff, 2013).

The process should give stakeholders sufficient incentives to enter and stay in this process (Van de Kaa and De Bruijn, 2015). Generally, actors face numerous incentives (Blind and Mangelsdorf, 2016), but are often unable to participate due to insufficient resources even though they are affected by the standard (Hills, 2000; Jakobs, 2006). Unfortunately, this is frequently the case for the wider public (Forsberg, 2012; Timmermans and Epstein, 2010). As a result, a standard's adoption can suffer from a lack of input as some needs are unmet (Foray, 1994). Standards need support from a critical mass and therefore naturally rely on a certain degree of inclusion. The marginalisation of population segments throughout standardisation is sometimes addressed by sponsoring 'volunteers' (Lehr, 1992) or by including various (e.g. user) coalitions (Foray, 1995; Hills, 2000; Markus et al., 2006). In the former, financial dependencies might influence the negotiation dynamics, whereas in the latter, resources can be merged to forge a more influential voice during negotiations.

4.2.3. Reflexivity and standardisation

Reflexivity refers to the ability of actors to apprehend how their activities, commitments, assumptions, and limited knowledge influence the development process. It considers how some perspectives might not be aligned with those of society (Fraaije and Flipse, 2020; Stilgoe et al., 2013). Reflexive standardisation requires detailed scrutiny of both this misalignment and the governance of standardisation processes itself. The literature on reflexivity distinguishes between first-order and second-order reflective learning. The first refers to the "consideration of problem definitions and evaluation of solutions" (Grin and Van De Graaf, 1996, p. 299) in light of the current value system and background theories (Van de Poel and Zwart, 2010). It is therefore concerned with improving standardisation based on the current notion of what responsible processes are. In second-order reflective learning, "value systems become the object of learning while in first-order learning these are taken for granted." (Schuurbiers, 2011, p. 772). This meta-reflection can redefine the value system and challenge actors' notion of responsibility. These two reflections hence consider the role and societal responsibility, respectively.

Standards are not merely the outcome of economic rationality but also the product of institutional values (Nickerson and zur Muehlen, 2006). Aligning values through reflective learning can be achieved by involving external stakeholders throughout the process and connecting and comparing their values with those of the committee. A lack of reflective learning in standardisation may be self-destructing (Hanseth et al., 2003). An example is the chosen human standard in biomedicine during the 1980s. White middle-aged males were the norm in biomedical experiments, while other groups were underrepresented. This consequently led to a resistance movement that disputed this practice (Timmermans and Epstein, 2010).

While inclusion enriches negotiations (De Bruijn and Ten Heuvelhof, 2008), it additionally complicates reflective learning by adding complexity (Hanseth et al., 2003). This suggests an inverse U-shaped relationship between inclusion and reflexivity: inclusion allows for reflective learning, but too much of it complicates and thus hampers this reflective learning.

4.2.4. Responsiveness and standardisation

Responsiveness means adequately reacting to insights acquired through anticipatory, inclusive, and reflexive activities (Stilgoe et al., 2013) to mitigate risks and seize opportunities (Pellizzoni, 2004). A responsive standardisation process continuously internalises input, demonstrates flexibility, and co-evolves with its changing environment. As such, standardisation is an iterative process of standard establishment and diffusion (Botzem and Dobusch, 2012). The frequency at which, and extent to which, a standard changes over time is captured by the notion of *standard flexibility* (Egyedi and Verwater-Lukszo, 2005; Van den Ende et al., 2012). This concept appears paradoxical as standards aim to provide compatibility through stability. However, flexibility can lead to a greater acceptance and stability of the standard in the long term (Van den Ende et al., 2012). Nevertheless, changing standards is made more challenging by network externalities (Callon, 1987), lock-in effects (Cowan, 1992), and standard complexity (Hanseth et al., 1996). Although responsiveness ought to be crucial for RI, there is a prevailing concern about too much flexibility (Egyedi, 1999; Hanseth et al., 1996). Some scholars solicit balance between stability and flexibility (Timmermans and Epstein, 2010), but it is unclear what exactly this entails. Along these lines, there is a tension between responsiveness and the stability of standards.

4.3. Method

This study examines the extent to which RI is institutionalised in *de jure* standardisation. It does so by adopting the AIRR framework as its theoretical lens. Subsequently, it derives a practical understanding of responsible standardisation and the factors that might obstruct, facilitate, and motivate the four AIRR dimensions in the national *de jure* standardisation process.

As part of our method, the case of the Royal Dutch Normalisation Institute (NEN) was chosen to address the research aim of this study. NEN has been operational since 1916, and is a relatively large SDO. Its mission is to establish consensual, widely adopted, and socially desirable standards (NEN, 2021). The latter may imply that this SDO values and exhibits morally responsible process characteristics. Furthermore, this case's national character could accommodate for a relatively homogeneous (e.g. institutional) unit of analysis. Both these aspects contribute to a rich research environment.

This study deployed a mixed research method (Table 4-1). First, unstructured orientation interviews with various NEN employees (three consultants and two mid-level managers) were conducted to contextualize the study and gain familiarity with the SDO. This understanding allowed for the bridging of the academic concepts of RI to the practical context of standardisation. This is crucial as the implementation of RI is context-dependent (Jakobsen et al., 2019). Hereafter, in-depth semi-structured interviews with a large proportion of the management (one mid-level, and four high-level managers) were conducted to acquire qualitative insights on what responsible standardisation means to the SDO, how its current practices relate to the four dimensions of interest, and what factors motivate, hinder, or facilitate these. The interview questions can be found in Appendix C.1.. The semi-structured interviews were transcribed and then analysed for any potential aspects that affect the four dimensions. The aspects (codes) were aggregated to factors (themes) affecting the four

AIRR dimensions (categories). Data collection continued until thematic saturation was assumed (Figure 4-1) – 96 factors were identified after the last interview. All interviewees had extensive working experience at NEN, ranging from six to thirty years, with ample operational and management experience. Their perspectives are expected to be representative of the higher management.

Table 4-1: Overview of research process.

Phase	Goal	Method	Length	Respondents	N
1	Orientation	Unstructured interviews	1 hour	3 Consultants 2 Mid-level managers	5
2	Exploration	Semi-structured interviews	1 – 2.5 hours	1 Mid-level manager 4 High-level managers	5
3	Validation	Survey	25 min	Consultants	28

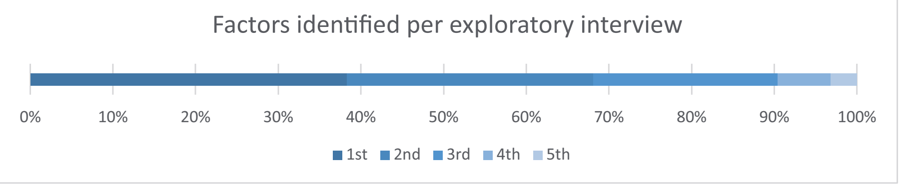

Figure 4-1: The proportion of factors identified per semi-structured interview, suggesting thematic saturation.

Next, the factors identified through interviews have been validated/rejected by means of an anonymous survey sent via email. These were deployed among the SDO's consultants (n≈100) of which roughly 1/3 responded. The consultants' main task is to facilitate the standardisation process at the operational level with a chairperson's help. The consultants thus experience standardisation first-hand. They were asked to what extent they agreed with the factors by rating them on a 5-point Likert-scale[11]. Other committee members could not be contacted due to privacy regulations. However, the nature of the consultants' work provides them with a sufficient understanding of standardisation processes to validate or reject any process factor of interest. These mixed methods map the experience and perspective of both the 'top- and bottom-layer' of the organisation, which uncovers discrepancies. The results are described in the following section.

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11 By answering: completely agree (1), partly agree (2), neutral (3), partly disagree (4), completely disagree (5), or 'prefer not to answer' or 'don't know'.

4.4. Results

96 Factors were identified utilizing exploratory interviews (see Appendix C.2.). An elaboration per factor, per dimension, is given below. These factors are referred to as lMn (motives), lBn (barriers), and lFn (facilitators), with l referring to an RI dimension (anticipation, inclusion, reflexivity, responsiveness) or responsible standardisation in general. n refers to the number of the respective factor. Appendix C.2. indicates to what extent the consultants recognised the factors. This section first describes what responsible standardisation entails according to the SDO. Hereafter, the RI dimensions' results are reported, followed by a summary of the survey results.

4.4.1. Responsible standardisation

According to the SDO, responsible standardisation is a process that establishes socially desirable standards. These standards make the world better, for example, by contributing to the environment, safety, and health. Suggested normative requirements for such a process are that all relevant stakeholders can participate, actively provide input, and that the process is transparent. All stakeholders should contribute to the standard's development to create broad support. Respondents argued that standardisation strives to be responsible but that the role of an SDO is principally limited to neutrally facilitating the process while committee members determine the course and the outcome. This poses a dilemma. On the one hand, the SDO intends to be a neutral facilitator that only brings parties together and mediates between them. On the other hand, it recognizes that this might not be adequate for creating responsible standards.

Multiple motives to standardize responsibly were disclosed. Standards can affect technological developments and therefore substantially impact society. Furthermore, the SDO has an influential market position. Hence, the SDO's role comes with a responsibility (SM1), which, according to the managers, NEN is also intrinsically motivated to meet (SM2). Respondents also indicated that committees are motivated towards responsibility out of their own interest (SM3) as members are affected by their standards.

Responsibility is instrumental to the organisation's reputation as it provides credibility (SM4) in a continuously scrutinised environment. Socially desirable standardisation is believed to be inherently consensual and leads to increased market acceptance (SM5). When a consensual outcome is established collectively, then this assumedly leads to the best solution for the problem at hand (SM6). The international standardisation community considers standardisation as a tool for reaching the UN's Sustainable Development Goals (SDGs; SM7). However, all committee members have their own agenda and reasons to initiate or be engaged in the standardisation process. The SDO's influence on the outcome is therefore limited.

4.4.2. Dimensions of responsible standardisation

Inclusion: Institutionalisation

Historically, industries established the SDO to facilitate agreements between industrial parties. Only around the 1990s did parties become aware of the value of including consumers. Although considerable effort is allocated to inclusion, all managers agreed that there was room for improvement. The average contemporary committee size was estimated to be ten to twelve stakeholders. These represent large groups of potentially affected actors. However, some standards are used by thousands of adopters. This poses the question of whether committees are inclusive enough. Respondents also mentioned that committee compositions should be more gender diverse and include "[economically] weak stakeholders" such as start-ups and activists.

Inclusion: Motives

Inclusion is a requisite for responsible standardisation (IM1). An inclusive committee represents society's interests to ensure the outcome is desirable and, hence, adopted (IM2). One of the managers stated: "If it is not supported by society, then there is no point in continuing the process at all". Inclusive committees benefit from their members' relevant know-how, resulting in better standards (IM3). This is claimed to be essential, as the SDO is not an expert on the content. An SDO is an expert in bringing parties together and mediating between them. If done well, the adopters of the standard are expected to feel as if they established the standard themselves, which causes them to perceive it as a logical solution (IM4). Inclusion is a primal need as stakeholders determine what a valuable standard is. It is not merely the standard that is valuable. The committee's stakeholder network also provides value on itself (IM5), e.g., knowledge exchange.

Inclusion: Barriers

Various factors form barriers to inclusion. Stakeholders are not always aware that a standardisation process exists (IB1) or lack awareness of its importance (IB2). They can have difficulties in finding relevant standardisation processes and already established standards (IB3). They are not always able to be involved effectively (IB4), for example, due to power inequalities among committee members (IB5). Stakeholders are often unable to evaluate the benefits that parties have gained through involvement in standardisation (IB6). Other barriers include lack of time (IB7), priorities (IB8), or interest (IB9). A simple invitation from an SDO to the relevant stakeholders is often not enough. According to all managers, NEN's business model is undoubtedly a barrier to inclusion (IB10). Stakeholders are required to pay a participation fee which impedes some stakeholders from joining. Subsequent expenditures (e.g., travel costs) increase this hurdle. Some stakeholders lack adequate knowledge (IB11) and some falsely assume their own shortcomings (IB12). The technical nature of standardisation (IB13) only adds to these last two barriers. Managers admitted that getting the last 20% of actors on board can take 80% of the effort. An SDO might also have difficulties understanding the role of stakeholders (IB14). A philanthropic organisation, for example, can be an extension of an industrial party. It is then not always clear whether this party acts on behalf of the charity or the industry. Occasionally, committee members might show resistance to more, or specific, new members (IB15). If the committee's composition is inadequate, a less formal standard type can be chosen that does not require full stakeholder representation or consensus. The type of standard thus corresponds with the degree of inclusion (IB16). Alternatives to formal standards are national practice guidelines (NPR), national technical agreements (NTA), and the fast track standard (NEN-spec).

Inclusion: Facilitators

Various facilitating factors could increase the inclusion of standardisation. A prevalent factor is financial support for weak stakeholders (IF1). 'Stronger' stakeholders and the government could provide this support. However, one of the managers stated: "The simple assumption is that we should open up and allow everyone to freely take part in it [standardisation]. You'll remove barriers… but it's definitely not the complete solution". Another possible factor is managing expectations (IF2). Stakeholders must realise that standardisation should be an inclusive and consensual process rather than a one-party-centred-service. Besides, technology could play a facilitating role (IF3). The COVID-19 pandemic has shown that virtual meetings cost less, take place more frequently, and increase the participation of weaker stakeholders. It is unclear whether an entirely virtual process would be optimal as some interaction in person sparks a necessary mutual understanding. Moreover, inclusion by membership is not the only solution. Other forms of participation, such as public consultations, could increase engagement without demanding total commitment (IF4).

Anticipation: Institutionalisation

The common assumption is that if processes are inclusive enough and all interests are represented, then negative impacts will be anticipated and mitigated. However, not all standardisation processes are inclusive enough to do so, nor are all actors always able to anticipate the effects on behalf of their party (competently and effectively). The international context is claimed to be different. ISO standardisation must describe how the standard relates to SDGs and other challenges. This is difficult because the link between a particular, esoteric, and technical standard and its broader technological, economic, societal, and environmental impact is not self-evident. "Even when you are standardising a bolt, you'll have to elaborate on the economic and social impact. Often these questions are utterly difficult to answer". Answering these inquiries in the national standardisation is not obligatory for committees. Here, ultimately, it is a gut feeling associated with a specific topic that prompts a standard's ethical questions. For example, Artificial Intelligence (AI) is perceived as morally alarming, whereas an ICT system might not evoke the same concerns. Although standardisation considers 'simple use' and 'misuse' of standards, no comprehensive anticipatory study is conducted.

Anticipation: Motives

Anticipation is motivated by the belief that it is necessary to create socially desirable standards (AM1), increase market adoption (AM2), and ensure quality (AM3). It could also prolong the relevance of standards (AM4). Although committee members could be intrinsically motivated to anticipate the impacts (AM5), it is of paramount importance that an SDO determines and agrees on the role that it intends to fulfil. Does it merely intend to be a neutral facilitator/mediator and rely on the committees' willingness? Or will it stimulate the committee to conduct anticipatory activities? This is a topic of discussion for the SDO.

Anticipation: Barriers

Generally, anticipation is voluntary and thus requires willingness (AB1), which depends on the composition of the committees (AB2). Members may lack technical knowledge (AB3), financial resources (AB4), and anticipatory skills (AB5), which can obstruct anticipation. Moreover, members are not always aware of the current state of affairs (AB6) and the likely outcome of the process (AB7). The nature of standards (AB8) and their versatile use can hinder anticipation (AB9). As an example of the latter, standardising geographic maps might not have an apparent controversial impact, but these standards are essential for warfare missile systems. The standard's use might only become apparent in hindsight. Even if members are willing to anticipate, their capacity can suffer from a lack or superficiality of anticipatory tools (AB10).

Anticipation: Facilitators

First, inclusion could increase the committee's anticipatory capacity (AF1). Second, managers mentioned that technology could increase the process' transparency so that public scrutiny can hold committees more accountable for their actions (AF2). This might incite anticipation. A fully transparent process is challenging to achieve as committee members are frequently inclined to disclose sensitive or classified information pertinent to the standard. Maintaining information asymmetries is namely crucial for the competitive advantage of many members.

Reflexivity: Institutionalisation

Reflective learning is done both proactively and reactively, and both in the first-order and second-order. The SDO's decisions predominantly relate to including stakeholders and establishing consensus. Therefore, these aspects undergo most first-order reflection. A managers stated: "We continuously assess the composition of the standardisation committee. For this, we use a stakeholder analysis. We consider which societal aspects are relevant, which parties relate to these aspects, and how we could involve them". Moreover, committees are requested to reflect on their completeness and to provide feedback on the SDO's services. Employees are trained and assessed on their performance through an internal academy, a complementary mentor, and a monitoring policy committee. The members are also guided by a consultant, organisational statutes, codes of conduct, and regulations. The latter three are considered safety nets. The SDO is a member of international organisations, which impose additional quality criteria, e.g. committee composition requirements. Standards always enjoy a period of public scrutiny before publication, and external events frequently trigger reflective discussions on how these relate to the committees. One manager provided an example: "The huge Schiphol Airport fire was, of course, horrible. It led to questions in our committee [fire safety] on what our role is in this. Could we have prevented this? Can this be solved with standards?". Although reflective mechanisms are in place, the committee's reflective capacity is still partly dependent on its members' willingness and initiatives.

Reflexivity: Motives

The SDO and its committees reflect on their actions as this is assumed to be essential for increasing the social desirability (RM1) and market adoption of standards (RM2). This suggests that reflection is at least partly motivated instrumentally.

Reflexivity: Barriers

Barriers to reflexivity are a lack of inclusion (RB1) and transparency (RB2), the ambiguous interpretation of codes of conduct (RB3), the hidden agenda of committee members (RB4), and the complexity of the standardisation process (RB5). Reflective learning is also more complicated at the organisational level than in a single committee as standardisation contexts differ in terms of sector and topic (RB6). It is hence hard to comprehend the generalisability of lessons learned in one committee to other committees. Likewise, reflecting on standards' impact is also difficult as an agreed upon definition or impact assessment is lacking (RB7).

Reflexivity: Facilitators

Although misinterpretation of formal rules, guidelines, and processes can obstruct reflexivity, these mechanisms are principally established to enhance this (RF1). Evaluation tools (RF2), training (RF3), external controlling bodies such as ISO (RF4), and internal bodies such as a policy committee (RF5) can increase reflective capacity. Furthermore, technology can facilitate public scrutiny, stimulate inclusion and transparency, and hence incite reflective activities (RF6). External incidents can also trigger reflection (RF7). Perhaps more critical is the committees' awareness of their moral obligation to society, and that their actions will affect everyone in the standard's system (RF8).

Responsiveness: Institutionalisation

Reaching consensus is a lengthy process that can take three to four years. Some sectors require a faster pace than others considering differences in the rate of technological change. Processes can be cancelled if they exceed the predetermined time frame. A standard is re-evaluated every five years if no earlier request is made. All managers admitted that this is too long, but also necessary for attaining consensus and stakeholder support. If this is not required, then an NTA, NPR, and NEN-spec are quicker alternatives. Although these can provide a faster solution to problems, they are not likely to respond adequately to all stakeholders' needs and values and will therefore lack full support. An example of an alternative standard is the 'non-medical facemask for public use' (NEN-spec 1) established in a record time of three weeks as a response to COVID-19. This was partly possible because consensus was not (yet) a hard requirement. Rather, an accelerated agreement on the masks' quality was prioritised. This presented disadvantages as some dimensions appeared incorrect. However, the NEN-spec can compensate for potential flaws by its six-month expiration period. The standard must then either be improved, terminated, or upgraded to e.g., a formal standard. An advantage is that committees do not have to start from scratch.

Responsiveness: Motives

Initiating a standardisation process is motivated by the notion that society is better off when aspects are uniformly agreed upon (ResM1). Standards can also be a response to SDGs (ResM2). Yet, calls for standards are not automatically rejected for the simple reason that they are not beneficial for society. The committee on smoking is an example. Although its contribution to society may be questionable, the law ultimately confines the scope of the SDO's activities.

Responsiveness in standardisation is furthermore essential because it requires a genuine appreciation and internalisation of every input to achieve consensus (ResM3), ensure quality (ResM4), and increase market acceptance (ResM5). Calls for formal standards are occasionally rejected based on the belief that consensus appears unattainable. If parties do not seek consensus, they should not establish a standard as it would limit its adoption. Once a standard is established, responsiveness is critical to ensure that the standard's value is maintained (ResM6).

Responsiveness: Barriers

Responsiveness may also mean to not do, or discontinue, something. But there are no clear requirements for when to do so (ResB1). One manager referred to the committee for sustainable proteins (e.g., peas, crickets). Although its work is beneficial for the environment, it can also be detrimental to the incumbent industry for conventional proteins (e.g., eggs, meat). It is not always evident what role an SDO should play in these transitions. No protocols are in place to cope with these market dynamics.

The time-to-consensus is dependent on the committee. Conflicting goals (ResB2) and hidden agendas of committee members (ResB3), the complexity of the standard

(ResB4), last-minute participators (ResB5), emotionally involved parties (ResB6), and conflicting fundamental values (ResB7) are all factors that can slow down or hinder consensus. One of the managers gave an example: "It [the European standard committee for halal food] led to a discussion about the interpretation of the Quran. Seeing that this concerns the very fundamental life philosophies of individuals, we ultimately concluded that consensus was unattainable". Some topics are therefore also less susceptible to consensus (ResB8).

Inclusion also poses a dilemma concerning responsiveness (ResB9). Too little inclusion might accelerate the process of consensus but result in possibly excluding important insights. It could induce a misleading belief that the achieved consensus emanates societal support. Excessive inclusion might provide all input, but negotiations presumably prolong and could exceed the predetermined time limit. The SDO struggles with this. When, despite efforts to include a wide range of actors, the diversity of parties is too limited, a possibility would be to terminate the process. However, this is not always an option because the national SDO does not enjoy full autonomy (ResB10). Being a member of the European Committee for Standardisation (CEN), for instance, comes with both benefits and dependencies. If a European standard is developed, it is by definition applicable in all member states. This, therefore, compels nations to participate.

After standards have been established, flexibility may become challenging. Responsiveness covers adjusting standards to changing needs, values, and environments. Nevertheless, not all parties are willing or able to adjust their innovations. Standards intend to provide stability, not constant change. Ergo the desire for stability (e.g., due to sunk investments) may hinder responsiveness (ResB11).

Responsiveness: Facilitators

Factors that can shorten the time-to-consensus are the meeting mode (e.g. virtual; ResF1), the type of standard (ResF2), governmental pressure (ResF3), societal pressure (ResF4), the severity of the problem at hand (ResF5), the willingness of members to compromise (ResF6), group cohesion (ResF7), members' realistic expectations of standardisation (ResF8), the frequency of meetings (ResF9), and a sense of urgency (ResF10). The facemask standard as a response to COVID-19 is a good example. It was established in record time as government pressure, the severity of the problem, and the sense of urgency influenced the willingness to compromise. As mentioned, the NEN-spec does not require complete consensus nor full stakeholder representation. The additional shift to virtual standardisation led to more effective and frequent meetings. Generally speaking, national standardisation affects responsiveness positively as it allows the national SDO to have more control in the process (ResF11). Finally, the sector type influences the time-to-consensus and the rate at which the standard needs to be improved (ResF12). The chairperson's mediating competencies additionally affect the speed of standardisation (ResF13). The chair is not an SDO employee and is sometimes chosen based on technical expertise rather than coordinative skills. The mediator should be able to pinpoint the root cause of disagreements and "peel the layers of the onion one by one". However, finding a willing candidate to take on this role is often challenging. The chair person is namely obliged to be neutral and invest more time.

4.4.3. A bottom-up perspective

Consultants were asked whether *de jure* standardisation is, in their opinion, responsible enough to establish socially desirable standards. Notably, a large proportion disagreed that this is the case (see Figure 4-2). Furthermore, they appeared sceptical on whether standardisation is inclusive and anticipatory enough. The results are less evident on the reflective and responsive capacity of the process.

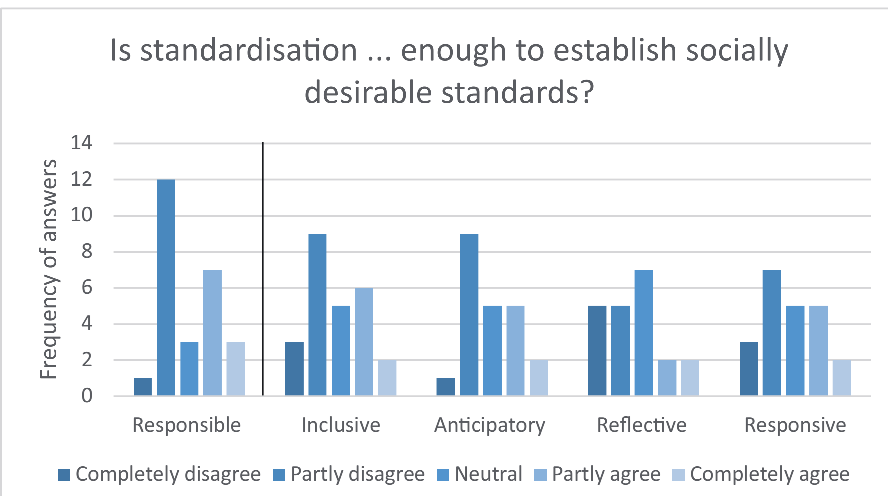

Figure 4-2: The consultant's perspective on whether standardisation is capable of establishing socially desirable standards.

Based on the survey's median values for the 96 factors, none of the factors were categorically rejected. The medians indicate that consultants 'completely agreed' with the presence of 16 factors, 'partly agreed' with 58 factors, and were 'neutral' about 22 factors (see both Table 4-2 and Appendix C.2.). No new factors were identified through the survey.

Table 4-2: Overview of the survey's results. To what extent do consultants recognise the presence of the identified factors.

Dimension	Result survey (based on median)	Motives	Barriers	Facilitators
Responsible standardisation	Completely agree	2	N/A	N/A
	Partly agree	4	N/A	N/A
	Neutral	1	N/A	N/A
Inclusion	Completely agree	3	2	0
	Partly agree	2	7	4
	Neutral	0	7	0
Anticipation	Completely agree	3	0	0
	Partly agree	2	8	1
	Neutral	0	2	1
Reflexivity	Completely agree	0	0	1
	Partly agree	2	4	5
	Neutral	0	3	2
Responsiveness	Completely agree	1	0	4
	Partly agree	3	8	9
	Neutral	2	3	0
Total		25	44	27

4.5. Discussion and Conclusion

This study examined the extent to which the procedural dimensions of RI are institutionalised in the process of *de jure* standardisation and identified 96 factors that might motivate, hinder, or facilitate these four dimensions (Appendix C.2.). Sixteen of these form a set of most prevalent factors (Appendix C.3.).

The SDO defines responsible standardisation as a process that establishes socially desirable standards. It recognises its moral obligation to society in facilitating such processes and deliberately reflects on re-shaping its organisation to accommodate this. This study shows that anticipation, inclusion, reflexivity, and responsiveness are motivated, and thus perceived to be necessary to meet this obligation (Figure 4-3). Besides, respondents believe that it could provide other significant benefits as well e.g. increased legitimacy, quality, and market acceptance of standards. However, RI's extensive institutionalisation remains problematic for the following reasons.

First, the SDO tends to profile itself as a neutral facilitator. In contrast, RI might require to discard this division of moral labour and, for example, to proactively guide committees to engage in anticipatory activities. Therefore, there may be a tension between the SDO's neutrality and RI. An additional tension is found in the committees as members have both obligations associated with their role and obligations towards society (Grinbaum and Groves, 2013).

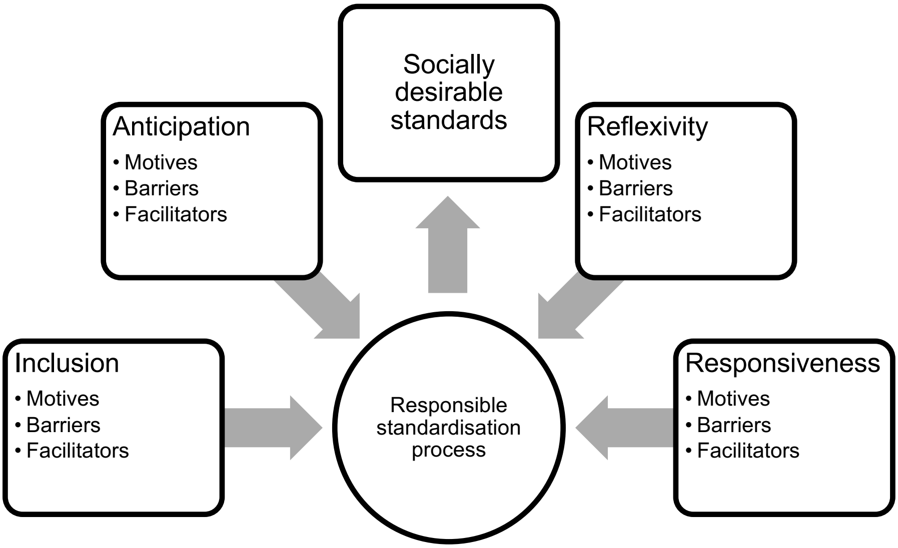

Figure 4-3: A conceptual framework for RI in the process of de jure standardisation.

Second, a large number of respondents indicated that standardisation might not be responsible enough to establish socially desirable standards. Aligning the role and societal responsibility can be difficult. If parties pursue the four dimensions, numerous factors might impede this effort. For example, our results suggest that transparency can incite reflexive and anticipatory behaviour. Yet, this seems unattainable as information asymmetries (e.g. Akerlof, 1970) remain important for the (sustained) competitive advantage of companies (Barney, 1991). Safeguarding this advantage is important for coopetition (Chiambaretto et al., 2019).

Third, respondents believe that if all stakeholders participate and represent their own interest, then all negative impacts will be mitigated in the process of reaching consensus. It is nevertheless unclear how this resolves, what is known in the literature as, the problem of many hands (Thompson, 2005), that is, the phenomenon that it is sometimes difficult to assign responsibility if a large number of people is involved in some activity. This may leave some important tasks unaddressed (Van de Poel et al., 2012). Hence, it seems unlikely that the AIRR framework suffices in adequately governing the standardisation process.

Fourth, the SDO and its committees are ill-equipped to meet the requisites of a responsible process. For instance, the lack of anticipatory skills and protocols leaves the committees empty handed. It is principally their gut feeling which indicates that emerging technologies such as AI require more attention than a simple bolt. How, and when, to anticipate remains therefore unclear. A clear definition of impacts is likewise absent. Although 'hard impacts' (quantitative) may come to mind, it is important not to overlook 'soft impacts' (qualitative; van der Burg, 2009). Identifying these might only become more difficult due to the versatility of a standard's use and the novelty of future challenges that may arise. Like the deficiency of the other dimensions, the lack of anticipation makes responsiveness only more important as standards need agility in response to flaws that appear. From an evolutionary perspective, responsiveness is needed to accommodate for technological change, but allowing for flexibility is difficult as standards principally intend to provide stability (Van den Ende et al., 2012). Hence, a balance needs to be found between stability and flexibility.

Fifth, along the lines of the evolutionary economics tradition, we find that RI proves problematic in light of creative destruction (Schumpeter, 1934). RI requires a response to the interests and values of all parties. However, creative destruction inevitably changes the political order creating both 'losers' and 'winners'. Following some scholars' reasoning (Blok and Lemmens, 2015; de Hoop et al., 2016), standards that spur innovations that contribute to creative destruction could be regarded as irresponsible due to the negative impacts for the incumbent industry. This might need reconsideration, as creative destruction is generally perceived as necessary for long-term societal progress and wellbeing. In our case, the SDO had to take sides in the protein transition and refrain from neutrality. This confronts SDOs, and larger socio-technical systems, with a special moral lock-in (Bruijnis et al., 2015) – the conventional industry is unsustainable and considered unethical by some, but the alternative is also morally questionable.

While RI's institutionalisation is influenced by these aforementioned aspects, we find that RI dimensions are also dependent on the type of standard and sector. This raises the question how different agreements and sectors relate to the four dimensions, and when particular types of agreements are legitimised. In our study, for instance, NEN-specs are found to be more responsive while formal standards are found to be more inclusive. Mapping the different properties of the *de jure* standardisation 'toolkit' in different sectors could provide valuable practical insights for innovation governance and policy and therefore seems a promising topic for future research.

This study has explored the institutionalisation of RI in *de jure* standardisation. Although many scholars often assume that standards are socially desirable, our results suggest that this is not self-evident. Still, we find ourselves at the beginning of RI's institutionalisation in standardisation, and many research topics are left unexplored. As discussed above, this paper suggests that RI in practice occasionally proves itself problematic − prompting future research concerning concepts such as collective responsibility, foresight, market competition, and Schumpeterian patterns of innovation. Furthermore, this work complements existing research on moral legitimacy (Forsberg, 2012; Suchman, 1995), explicating the need for a better understanding of RI's institutionalisation in the context of organisations (Owen et al., 2021a) and innovation systems (Owen and Pansera, 2019).

5. Public Participation in Mission-oriented Innovation Projects[12]

5.1. Introduction

Research and innovation (R&I) can play a major role in addressing societal challenges such as climate change, pandemics, and security (European Commission, 2009). *Mission-oriented innovation policy* (MIP) is devoted to directing R&I to such challenges (Ergas, 1987; European Commission, 2018). A classic example is the 'man-on-the-moon' program (Nelson, 1974). Many contemporary challenges are nevertheless acknowledged to be *wicked*, meaning that they are associated with complexity, uncertainty, and contestation (Head, 2008; Rittel and Webber, 1973). They require insights and coordination among numerous actors to support system-wide sociotechnical transformations (Diercks et al., 2019; Kuhlmann and Rip, 2018; Schot and Steinmueller, 2018). In contrast to the traditional technology-focused notion of missions, increasingly more MIPs are associated with "an urgent strategic goal that requires transformative systems change directed towards overcoming a wicked societal problem" (Hekkert et al., 2020, p. 76). These MIPs are believed to be coordination mechanisms for aligning and mobilizing heterogeneous stakeholders around a shared goal (Janssen et al., 2021a).

Driving system-wide transformation requires cooperation between various stakeholders (Linder et al., 2016; Loorbach and Rotmans, 2010; Mazzucato, 2017, 2016; Rabadjieva and Terstriep, 2021; Wanzenböck et al., 2020). While research has focused on the private sector's participation in MIP (Kattel and Mazzucato, 2018; Mazzucato and Robinson, 2018), little research has focused on public participation (Diercks et al., 2019; Janssen et al., 2021a; Köhler et al., 2019). The involvement of public actors – here understood as non-conventional innovators like citizens (Schot et al., 2016), cities (Bulkeley and Casta, 2013), and NGOs (Kuhlmann and Rip, 2014) – is nevertheless crucial for the success of R&I processes in driving system-wide transformation (Haddad et al., 2022; Wanzenböck and Frenken, 2020; Weber and

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Rohracher, 2012) and in generating socially desirable outcomes (Stilgoe et al., 2013; Von Schomberg, 2013). If mobilising actors into a uniform direction is the aim of missions, then it is essential to understand how the participation of public actors takes place (Janssen et al., 2023).

However, there is a considerable gap between the literature on MIP and on public participation in R&I (Shanley et al., 2022). It remains unclear to what extent a mission-orientation encourages the involvement of publics. It is not known how public participation differs between mission-oriented and non-mission-oriented projects, and how missions differ amongst each other in this regard.

This study addresses these knowledge gaps and contributes to MIP theory and practice by quantitatively testing whether mission-oriented projects meet the normative aspirations of facilitating more effective public participation than conventional projects. By doing so, we gain insights into the participatory performance of mission-oriented projects. We identify characteristics that affect this performance, provide valuable policy recommendations, and specify promising future research avenues related to public participation and MIP.

The paper is structured as follows. Section 5.2. discusses a mission's main rationales for public participation. This study then follows Rowe and Frewer's (2004) suggestion to first define *effectiveness* of participation, which allows us to develop hypotheses in preparation for our analysis. Section 5.3. subsequently proposes an *operationalisation* of the respective effectiveness aspects as input for our *assessment* of missions-oriented projects. Section 5.4. then presents the results which are further dissected and discussed in section 5.5.

5.2. Theory

5.2.1. Missions and public participation

MIP stems from the notion that patterns of R&I are accumulative and that sociotechnical change is characterised by a rate and direction (Dosi, 1982; Kuhn, 1962). While change can be divergent (i.e. creative destruction) or convergent (i.e. creative accumulation; Schumpeter, 1934), MIP may guide these Schumpeterian waves through the selection of priority themes (Foray, 2018). Despite the fact that governments have deployed such 'selective' or 'preferential' national innovation policies for nearly a century (Cantner & Pyka, 2001; Chavez et al., 2017; Ergas, 1987; Roth et al., 2021), scholars argue that a renewed interest in MIP has emerged due to its potential for uniting actors around clearly defined goals in order to tackle wicked societal challenges (Janssen et al., 2021; Mazzucato, 2018a; Wanzenböck et al., 2020). Contemporary MIPs are frequently classified as 'normative' or 'third generation' innovation policies targeted at driving sociotechnical transformations (Schot & Steinmueller, 2018).

One target audience for these policies, as with earlier generations of innovation policies, are firms. Providing direction and perspective helps them to deal with the uncertainty and turbulence associated with impending transformations (Linton & Walsh, 2004). It encourages firms to assess which of their core competencies match emerging markets, and which of these are needed to develop a (sustainable) competitive advantage (Barney, 1991; Marino, 1996; Prahalad & Hamel, 1994). Such core competencies allow firms to "adapt quickly to changing opportunities" (Prahalad & Hamel, 1990, p. 4).

Apart from mobilising firms, attaining missions and driving transformations also requires participation from a broader set of stakeholders (Borrás and Edler, 2014; Diercks et al., 2019; Edler and Fagerberg, 2017; Kuhlmann and Rip, 2018; Schot and Steinmueller, 2018), including public actors (Bugge and Fevolden, 2019; Mazzucato, 2018b, 2018a; Surie, 2017). More specifically, various normative, instrumental, and substantive arguments in favour of public participation (Stirling, 2008) resonate with MIP.

Western scholars frequently adopt an oversimplified logic: "the technical is political, the political should be democratic, and the democratic should be participatory" (Moore, 2010, p. 793). Benefits associated with public participation include the opportunity for local publics to express, exchange, and act upon their values and worldviews (Bauer et al., 2021; Steen and Nauta, 2020; Sykes and Macnaghten, 2013). As a result, participation is arguably the right thing to do from a normative democratic perspective (Stirling, 2008).

Considering that missions are geared towards driving transformative change, instrumental and substantive arguments in favour of public participation can be made in relation to preventing and overcoming transformational system failures (Weber and Rohracher, 2012). For instance, public actors contribute to the social construction of technologies (Bijker, 1995; Pinch and Bijker, 1984), and thus influence how mission-oriented innovations are perceived and embedded in society. The literature on public participation assumes that the values and worldviews that guide R&I, and which affect their social construction, cannot be determined top-down or *a priori* but should be explored in inclusive deliberations with diverse societal stakeholders (Bauer et al., 2021; Genus and Coles, 2005). By means of co-production, the public's involvement can help mitigate demand articulation failures (Fisher et al., 2018; Surie, 2017), reflexivity failures (Garud and Gehman, 2012; Smith et al., 2014), and directionality failures (Grillitsch et al., 2019; Janssen et al., 2021a; Sykes and Macnaghten, 2013).

Missions are hoped to empower public actors to participate and contribute to mission-oriented R&I (Wanzenböck and Frenken, 2020). Although current literature pays ample attention to *creating* new missions, it tends to neglect the *process* of achieving them. In order to better understand the dynamics and governance of missions, research needs to investigate to what extent missions mobilise and empower the public (Janssen et al., 2021a).

While many scholars acknowledge the importance of including 'the public', the notion of the public itself is controversial and has different meanings in different academic disciplines (Pesch et al., 2020). Science & Technology Studies tends to refer to citizens and civil society organisations; Innovation Management frequently gravitates towards users and consumers; while Innovation Studies tends to include cities and governmental bodies. In this paper, our working definition for the umbrella term 'the public' refers to all these actors above and hence excludes conventional innovators, i.e., industry (e.g. incumbents and SMEs) and knowledge institutes (e.g. universities and research institutes).

Public participation is broadly described as an inclusive process that allows (potentially) affected actors to partake in the decision-making process of R&I (Newig and Kvarda, 2012; Rowe and Frewer, 2000; Smith, 1983). Although there are many forms of participation (Lynam et al., 2007; Reed et al., 2009; Rowe and Frewer, 2005, 2000), this paper focuses on forms that Arnstein (1969) labels as 'higher degrees of power'. As such, we understand public participation as public actors formally partaking in R&I projects by either having full control, delegated power, or influence through partnerships. The imperative of public participation in mission-oriented R&I raises the question to what extent missions encourage public participation and how this can be measured.

5.2.2. Measuring public participation

The challenges of measurement

Measuring public participation is challenging. Public participation is complex and contested in itself. There is no consensus on what evaluation criteria to use, no dominant evaluation method has emerged, and few reliable tools for measurement exist (Rosener, 1981; Rowe and Frewer, 2004). As a result, analyses are often context-dependent and rely on practicalities such as data availability. To deal with this, Rowe and Frewer (2004) propose to first define public participation's 'effectiveness' (1), to operationalize it accordingly (2), and to subsequently conduct the evaluation and interpretation (3). We adopt three dimensions inspired by Callon et al. (2009) that characterize the participation's effectiveness, and which have gained popularity in the academic discourse over the last decade. An advantage of these dimensions is that they particularly focus on the process of public participation rather than its creation or outcomes. These respective process dimensions are referred to as *intensity*, *openness,* and *quality*.

Intensity

The intensity of public participation refers to "how early laypersons are involved in research [and innovation]" (Callon et al., 2009, p. 158). Although innovation is a complex and iterative process containing feedback loops (Kline and Rosenberg, 1986), many simplistic and disputed linear models have emerged in the literature. These roughly share the proposition that R&I processes can be conceptualised into the following phases: basic research, applied research, invention, development, production, and diffusion (Godin, 2005; Godin and Lane, 2013). Early participation refers to the upstream stages of basic and applied research (Delgado et al., 2011; Wilsdon and Willis, 2004).

MIP frequently draws on novel, contentious scientific research in an early stage, to frame complex societal problems and envision potential resolutions (Schot and Steinmueller, 2018). Such scientific knowledge is often associated with many uncertainties, ambiguities, and unknowns (Stirling, 2010). Scholars therefore advocate upstream public participation to collectively confront the inherently imperfect foresight of experts and decision-makers and complement these with the public's knowledge, skills, and values (Jasanoff, 2003). As such, upstream participation can help MIP to deal with the Collingridge dilemma (Collingridge, 1980) − a lack of knowledge on how to govern, direct, and shape technologies before path dependencies (David, 1995, 1994), technological lock-ins (Arthur, 1989), and entrenchment occur (Collingridge, 1980). Public participation could therefore enable mission-oriented innovators to proactively respond to early concerns, values, needs, and expectations of the public before this becomes problematic (Genus and Coles, 2005; Stilgoe et al., 2013). A vivid example is the climate geoengineering SPICE project that showed that the expression of societal concerns in early participation can lead to more anticipatory and reflexive research practices (Pidgeon et al., 2013; Stilgoe et al., 2013). As a result, many scholars have advocated for high intensity public participation (e.g., Chess and

Purcell, 1999; Kearnes et al., 2006; Mazmanian and Nienaber, 1980; Reed, 2008; Rowe and Frewer, 2000).

On this account, early participation is considered favourable or even the norm for projects that induce transformative change. One might therefore expect that mission-oriented projects are characterised by earlier participation than non-mission-oriented projects. As a result, this paper aims to test this by hypothesizing the following:

Hypothesis 1: Mission-oriented projects exhibit public participation in an earlier phase than non-mission-oriented projects.

Openness

Openness refers to the ease of partaking in the R&I process and can be measured by the number and diversity of public groups participating (Callon et al., 2009). The vast literature on open innovation has demonstrated that there is much to gain from involving different types of actors in R&I processes (Huizingh, 2011; van de Vrande et al., 2009; West and Bogers, 2014). Successful innovations need diverse stakeholder participation to obtain a broad range of values and worldviews that reflect those of society (Bugge and Fevolden, 2019; Diercks et al., 2019; Schot and Steinmueller, 2018).

Mission-oriented projects that drive transformative change can face contestation if they lack the necessary legitimacy (Edler and Boon, 2018; Wanzenböck et al., 2020). Openness can provide this legitimacy, as diversity is essential for attaining moral legitimacy (Suchman, 1995), input legitimacy (Scharpf, 1999, 1997), and throughput legitimacy (Schmidt, 2013). Diverse input can also lead to better decision-making (Beierle, 2002; Koontz and Thomas, 2006; Newig, 2007; Newig and Fritsch, 2009; Reed, 2008; Stahl, 2013; Stirling, 2010), hence providing output legitimacy (Scharpf, 1999, 1997).

Open participation is essential for mission-oriented projects as it can bring to light a variety of concerns (Latour, 2004) and emotions (Roeser, 2012) and therefore reveal possible value conflicts (Smith, 2003). By extension, innovators can better understand the meaning of social desirability (Owen et al., 2012) and align their role-specific activities with their societal duties (Grinbaum and Groves, 2013).

Addressing societal challenges requires open reflexive processes in which diverse actors challenge the purpose, process, and (long-term) implications of R&I in light of uncertainty and complexity (Ferraro et al., 2015; Schot and Steinmueller, 2018; Stilgoe et al., 2013; Weber and Rohracher, 2012). Consequently, openness is necessary to identify risks (Sykes and Macnaghten, 2013; Van den Hoven et al., 2013) and opportunities (Fraaije and Flipse, 2020; Sutcliffe, 2011), and to stimulate so-called 'deep learning'. Outside perspectives can enhance the reflective and anticipatory capacity of innovation processes (Fraaije and Flipse, 2020; Stilgoe et al., 2013) and therefore aid in overcoming reflexivity and demand articulation failures (Weber and Rohracher, 2012).

Based on MIP's rationales for openness, one might expect that these projects are open to a higher number, and a more diverse group, of public participants than non-mission-oriented projects. We test this by hypothesizing the following:

Hypothesis 2a: Mission-oriented projects have a higher number of public participants than non-mission-oriented projects.

Hypothesis 2b: Mission-oriented projects have more diverse public participants than non-mission-oriented projects.

Quality

Quality refers to the gravity of participation and the extent to which the public can push their ideas into innovation (Callon et al., 2009). It directly relates to the public's influence on decision-making (Fiorino, 1990; Reed, 2008) in mission-oriented projects. Influence contributes to the public's ability to shape technological developments and largely stems from their available resources (Rowe and Frewer, 2000). Wanzenböck & Frenken (2020) hint that missions require a decentralised empowerment of local stakeholders to better understand the contextual manifestations of challenges and better develop the contextual resolutions for these. Although bottom-up innovators tend to understand the local needs, perspectives, and values better, they often lack the resources to sustain or fully meet these demands (Hossain, 2016; Seyfang and Smith, 2007). Providing the public with resources hence appears an important requisite for achieving missions. If enabled, the public could even develop resolutions on their own as user innovators (von Hippel, 2005, 1988) as opposed to being co-creators in processes of open (Chesbrough, 2003), open-source (Raymond, 1999), and participatory innovation (Buur and Matthews, 2008). Still, it is essential to consider the public's influence in light of other decision-makers, as inequality is a strong barrier to participation (Reed, 2008).

Due to the importance of the public's ability to redirect and shape R&I based on their values and experience vis-a-vis societal challenges, one might expect that the public has a more influential presence in mission-oriented projects than in non-mission-oriented projects. Assuming that influence in such projects is related to the volume of resources that participants commit (Rowe and Frewer, 2000), we hypothesize the following:

Hypothesis 3: In mission-oriented projects public participants have more influence than in non-mission oriented innovation projects.

5.3. Method

5.3.1. Research design & case description

This cross-sectional research aims to understand to what extent a project's mission orientation is associated with more effective forms of public participation (i.e., intensity, openness, and quality) compared to projects without a mission orientation.

We selected the project administration of the Dutch Public-Private Partnership Allowance (PPP-Allowance)[13] as our empirical basis. This policy instrument supports public-private innovation projects by offering an allowance based on 30% (previously 25%) of private investments made in earlier public-private innovation projects. An important requirement is that both the allowance-generating and the allowance-using projects should fit the scope of the Knowledge and Innovation Agendas (KIAs) that form part of the Dutch national innovation strategy. This strategy originally consisted of the Topsector policy, launched in 2012 by the Ministry of Economic Affairs and Climate Policy and the Ministry of Education, Science, and Culture (Janssen and Abbasiharofteh, 2022). The initial Topsector policy aimed to promote and align the activities of research institutes with that of innovators by fostering coordination and collaboration in the Dutch science and innovation systems of nine sectors (e.g. energy and water technology). Over the course of 2017, it was announced that the Topsector policy would gradually be converted into the Mission-oriented Topsector and Innovation Policy (MTIP), which became effective from 2019 onwards. The MTIP focuses on four cross-sectoral themes (i.e., Energy Transition & Sustainability; Agriculture, Water & Food; Health & Healthcare; and Security) that collectively embody 25 concrete missions (Appendix D.1.). The MTIP, the KIAs, and therefore the innovation projects using the PPP-Allowance now target research programs that can contribute to achieving these missions (Janssen, 2020).

This case study is highly relevant for our research objective because the Netherlands is one of the forerunners in widely deploying mission-oriented innovation policies that address societal challenges. Studying the PPP-Allowance is particularly helpful because the government has compiled an extensive dataset regarding its

13 In Dutch: Publiek-Private Samenwerking toeslag (PPS-toeslag)

innovation projects and the missions that they are associated with. Hence, such a case study is helpful in testing our hypotheses (Eisenhardt, 1989).

The data on the content and scope of the collaborative innovation projects is provided by the Netherlands Enterprise Agency (RVO.nl). The full dataset contains information about all projects in the PPP-Allowance program from 2017 to 2019. This paper focuses on projects that started in 2017 or later. In 2017, organisations executing the PPP-Allowance have started to assign mission labels. These labels included in the dataset were refined via semantic techniques and extensive manual checks by RVO.nl, which acts as the central agency for collecting project information and storing it into a dataset in which also organisation names are homogenised.[14]

Although mission labels were assigned to projects from 2017 onwards, the actual shift from Topsector policy to MTIP only started to take shape in 2019. This implies that in the 2017-2019 period projects were hardly subjected to policies that actively promoted mission themes. Furthermore, the participation of public actors did not form a condition for the acquisition of funding. As a result, these aspects allow us to assess whether projects that innovate in line with missions have a *de facto* tendency to mobilise the public.

Examining this requires us to also take into account that projects in the PPP-Allowance scheme are created with the help of so-called Topconsortia for Knowledge and Innovation (TKI), which act as orchestrating entities in both the initial and current version of the national coordination-based innovation policy strategy. In their capacity as 'systemic innovation intermediaries' (Janssen et al., 2020), the TKIs operate as brokers between organisations that could complement each other in terms of the knowledge they can provide or that they are searching for. Each project is administered to RVO.nl by one of the 12 TKIs, that focus on a sectoral ecosystem (as they were established under the initial Topsector policy). In our analyses, we will control for the differential influence TKIs may have on project team formation and thus on public participation.

Besides information on whether a project fits a research program with relevance for missions (and if so, which mission), the dataset also contains details on issues such as project budget, technological maturity, the identity of formal participants, and their financial involvement in the project. Combining such project and project team characteristics allows us to construct variables on higher degrees of public

14 Some techniques for assigning mission labels were also applied retroactively before 2017, but since these techniques were less robust, we focus on the period for which we have the most reliable and consistent labels.

participation, i.e. whether public actors have full control, delegated power, or influence through partnerships.

5.3.2. Variables

Dependent variables: intensity, openness, and quality

As mentioned, this study measures public participation in R&I projects through three effectiveness indicators that form the dependent variables of our analysis, i.e., intensity, openness, and quality. *Intensity* relates to how early the public is involved in R&I. The dataset provides project-level data on its development stage and distinguishes between the stages 'fundamental' (upstream; Technology Readiness Level 1-3), 'applied' (midstream; Technology Readiness Level 4-6), and 'experimental' (downstream; Technology Readiness Level 7-8)[15]. A high intensity participation is therefore characterised by projects that formally involve public actors in upstream stages. The data contains information on the budget per phase. This paper considers *intensity* a nominal variable that indicates the earliest of the three developmental stages in which the public is financially committed to the respective project. *Intensity* can therefore refer to upstream participation (1), midstream participation (2), downstream participation (3), or no participation (4).

Openness refers to how easily the public can partake in projects and is suggested to be measured through the number and diversity of public participants (Callon et al., 2009). In order to do so, one first needs to define and classify the types of public actors that partake in R&I projects. Various stakeholder categorization methods and typologies have emerged in the last decades (e.g., Bianchi and Kossoudji, 2001; De Lopez, 2001; Mitchell et al., 1997; Savage et al., 1991). While stakeholder categorization is preferably done in collaboration with the stakeholders themselves (Reed et al., 2009), this was not feasible due to the size of the database.

Instead, we use the standardized organization classification (SBI-code) of the Dutch Central Agency for Statistics (CBS) to minimise biases. This code is a widely used multi-digit classification that links every registered organisation to a particular group according to their line of work. The first digit refers to the respective branch (e.g. healthcare) and the second digit indicates a subgroup (e.g., hospital, paramedical practice). SBI-codes are useful for this study because only registered organisations qualify for the PPP-Allowance. As a result, no *individual* actors, such as citizens, are

15 Technology Readiness Level (TRL) as based on the European Union H2020 2014 model, which was adapted from the former NASA TRL model (Héder, 2017).

reflected in the data. We retrieved the SBI-code per organisation from the dataset (Appendix D.4.) and computed the number and diversity of public participants.

Number is the count of organisations that classify as public participants. *Diversity* is computed by dividing a project's number of *unique* public participant types (*U*), as based on the SBI-codes, by the total number of organisations participating in the project (*T*). Unique public participant types concerns the number of different SBI codes, with multiple participants per SBI code counted as one participant type. Dividing *U* by *T* allows us to control for project team size. We thus test Hypotheses 2a and 2b by computing the differences between mission/non-mission projects in solely their *number* and their *diversity*, respectively.

The *quality* of public participation refers to the influence of the public in R&I projects. The economic influence is particularly important as investments directly contribute to the ability to influence decision-making and innovate in line with a mission. Influence is relative, hence the economic influence of the public should be considered in light of the economic influence of other actors. Therefore, this study uses the project's total public investments divided by the total investments as a proxy for *quality*.

Independent variable: Mission

We constructed an independent variable, *mission,* to understand how public participation in R&I projects differs between mission-oriented and conventional projects (see Table 5-1). This variable indicates whether a project falls under the category 'non-mission' (1) or one of the four mission themes, i.e., Energy Transition & Sustainability (2); Agriculture, Water & Food (3); and Health & Healthcare (4); Security (5); and insufficient information (6). These themes represent a constellation of coherent missions. As a result, this variable allows us to test whether mission-oriented projects indeed exhibit different degrees of public participation. Additionally, we also inspect whether public participation, as captured by our three measures, differs for the various mission themes.

Control variables

This study uses control variables to enhance the robustness of the analysis (Table 5-1). As mentioned, the TKIs at the heart of MTIP (formerly Dutch Topsector policy) act as brokers between parties in a particular domain (e.g. Delta technology). Because intermediaries contribute to network building, we control for *TKI* using the dataset's project categorisation, which classifies projects according to 12 TKIs with typically a sectoral orientation.

Further, as the topic of public participation may gain or lose prominence in society, the participatory performance of a project may change due to broader societal trends rather than whether or not public participants belong to a mission. Hence, we control for the *start date* of a project.

Table 5-1: Operationalisation table.

Variable type	Variable	Attribute	Scale	Definition
Dependent variables	Intensity		Nominal	Nominal variable indicating 'upstream participation' (1), 'midstream participation' (2), 'downstream participation' (3), or 'no participation' (4).
	Openness			Participation openness is composed of the aspects *number* and *diversity*.
		Number	Ratio	Count of public participants.
		Diversity	Ratio	Count of unique public participants (by SBI-code) relative to the total number of participants in a project.
	Quality		Ratio	Total public investments divided by total investments.
Independent variable	Mission		Nominal	Categorical variable indicating 'non-mission' (1), 'Energy Transition & Sustainability' (2); 'Agriculture, Water & Food' (3); 'Health & Healthcare' (4); 'Security' (5); and 'insufficient information' (6).
Control	TKI		Nominal	Classification according to 12 TKIs: Agriculture & Food (1), Biobased Economy (2), Chemical Engineering (3), Creative Industry (4), Delta Technology (5), Energy (6), High Tech Systems & Materials (7), Logistics (8), Life Science & Health (9), Maritime (10), Horticulture & Vegetative propagation (11), and Water Technology (12).
	Start date		Ratio	Year of the first project report as the proxy for the project's start year. This proxy is chosen as it is much more widely available compared to the project's start date.

5.3.3. Data analysis

The data analysis consists of four individual statistical analyses as we consider four dependent variables that each relate to one of the three dimensions of public participation, i.e., *intensity*, *openness* (*number*), *openness* (*diversity*), and *quality*. We estimate whether the variables, *mission* (themes), *TKI*, and *start date* correlate with the respective participation effectiveness indicators.

Intensity is estimated with a multinomial logistic regression, given that it is a categorical variable. The model provides the probability (0-1) that missions correlate with public participation in particular stages.

Openness consists of integer non-negative values. The Poisson distribution would be suitable to estimate this model but requires that variance and mean to be equal (Sun and Zhao, 2013). As the variable is overdispersed (variance exceeds the mean), we use a negative binomial model instead, which is more suitable in this case. *Number*, one constituent of *openness*, is the count of public actors in a project and consists of positive integer values. *Diversity*, the other constituent of *openness*, is a fraction that takes values in the unit interval, including 0 and 1, and is estimated with a fractional logistic regression (Papke and Wooldridge, 1996). This is a frequently used approach with fractional outcome variables (Adegbesan and Higgins, 2010).

Quality is the share of public investments in total project investments and takes values in the unit interval, including 0 and 1. Again, a fractional logit model is used to estimate the models (Papke and Wooldridge, 1996).

5.4. Results

This section first briefly describes the dataset and subsequently presents the results of the statistical tests per dependent variable, i.e. *intensity*, *openness*, and *quality* of public participation.

5.4.1. Descriptive statistics

Table 5-2 contains the summary project statistics of the ratio variables. Table 5-3 contains tabulations for the categorical variables. The data contains 1,261 projects involving 7,570 actors (6,896 conventional actors (91.1%) and 674 public actors (8.9%)). While 306 (24.3%) of these projects are not associated with a mission theme, 274 (21.7%) are linked to Energy Transition & Sustainability, 196 (15.5%) to Agriculture, Water & Food, 395 (31.3%) to Health & Healthcare, and 22 (1.7%) to

Security. On average, a project comprises 3.1 participants, of which 0.26 are public participants. Table 5.3 contains tabulations of the categorical variables.

Table 5-2: Summary project statistics of ratio variables.

Variables	Mean	Std. dev.	Min	Max
Openness				
Diversity	0.040	0.113	0	1
Number of unique public participant types (by SBI code)	0.179	0.461	0	4
Total number of participants	3.067	2.850	1	44
Number	0.265	0.828	0	12
Quality	0.040	0.125	0	1
Total public investment	34,868.55	323,556.4	0	6,850,000
Total investment	673,160.7	2,068,355	3889	48,900,000
Start date	2018.035	0.830	2017	2019

Table 5-3: Tabulations of categorical variables.

Variables	Frequency	Percent
Intensity		
1. Upstream participation	56	4.44
2. Midstream participation	135	10.71
3. Downstream participation	15	1.19
4. No participation	1,055	83.66
Total	1,261	100.00
TKI		
1. Agriculture & Food	54	4.28
2. Biobased Economy	23	1.82
3. Chemical Engineering	76	6.03
4. Creative Industry	23	1.82
5. Delta Technology	82	6.50
6. Energy	114	9.04
7. High Tech Systems & Materials	320	25.38
8. Logistics	332	26.33
9. Life Science & Health	31	2.46
10. Maritime	97	7.69
11. Horticulture & Vegetative Propagation	43	3.41
12. Water Technology	66	5.23
Total	1,261	100.00
Mission		
1. No mission	306	24.27
2. Energy Transition & Sustainability	274	21.73
3. Agriculture, Water & Food	196	15.54
4. Health & Healthcare	395	31.32
5. Security	22	1.74
6. Insufficient information	68	5.39
Total	1,261	100.00

5.4.2. Intensity

Given the nominal nature of *intensity*, several multinomial logistic regressions were run to understand the relation between a project's mission-orientation and the timing of public participation. Appendix D.2. contains a model with *intensity* as the dependent variable and the control variables *TKI* and *start date*, but not the independent variable *mission*. Appendix D.3. contains *intensity* and the independent variable, *mission*. Table 5-4, below, contains the full model.

The model containing controls only (Appendix D.2.) shows significant differences in participation across TKIs. For example, projects in the Maritime TKI are significantly less likely to have midstream participation than the base category, Agriculture & Food. Furthermore, the significant coefficients of *start date* show that more recent projects are less likely to have upstream and downstream participation compared to the base category, no participation.

Appendix D.3. shows the independent variables. It shows that projects that fall under the mission themes Energy Transition and Sustainability (2), Agriculture, Water & Food (3) and Health & Healthcare (4) differ from the base category, no mission. Security (5) is only weakly significant. Projects in mission 2, 3, and 4 are more likely to have upstream public participation, and projects in missions 2 and 3 are more likely to have midstream participation than projects without a mission, compared to the base of no participation.

The full model in Table 5-4 shows that across the board, the characteristic of mission-orientation – as opposed to non-mission-orientation – predicts upstream and midstream participation, except for *Security*. The finding that individual missions do not generally predict downstream participation can be seen as further support for the hypothesis that mission-oriented projects exhibit public participation in an earlier phase than non-mission-oriented projects.

Table 5-4: Intensity: results of the full model.

	(1)	(2)	(3)
	Multinomial logistic regression		
	Dependent variable: intensity (base level: 4. **No participation**)		
Variables	1. **Upstream participation**	2. **Midstream participation**	3. **Downstream participation**
Mission			
1. No mission			
2. Energy Transition & Sustainability	0.977	1.539***	-0.0145
	(0.988)	(0.486)	(1.472)
3. Agriculture, Water & Food	3.061***	1.521***	-11.51
	(1.033)	(0.570)	(947.0)
4. Health & Healthcare	2.200**	-0.483	1.075
	(0.940)	(0.726)	(1.197)
5. Security	3.185**	0.784	2.464*
	(1.378)	(0.904)	(1.363)
6. Insufficient information	0.304	1.128*	-14.75
	(1.192)	(0.627)	(1.522)
TKI			
Agriculture & Food (1)	0	0	0
	(base)	(base)	(base)
Biobased Economy (2)	-13.11	-0.759	-0.316
	(1.672)	(0.875)	(3.288)
Chemical Engineering (3)	1.404	-15.20	-0.721
	(1.312)	(629.7)	(2.292)
Creative Industry (4)	3.724**	1.260	15.70
	(1.452)	(0.875)	(1.627)
Delta Technology (5)	0.748	1.058**	1.022
	(1.184)	(0.477)	(2.271)
Energy (6)	3.436***	-0.422	15.08
	(1.230)	(0.588)	(1.627)
High Tech Systems & Materials (7)	0.442	-1.136*	13.35
	(1.294)	(0.619)	(1.627)
Logistics (8)	2.074*	0.985	14.37
	(1.196)	(0.731)	(1.627)
Life Science & Health (9)	-12.85	1.525**	-0.235
	(1.616)	(0.679)	(2.606)
Maritime (10)	1.401	-1.017	0.707
	(1.511)	(0.779)	(2.079)
Horticulture & Vegetative Propagation (11)	1.204	1.323**	1.420
	(1.261)	(0.529)	(2.890)
Water Technology (12)	1.396	1.291**	-0.558
	(1.258)	(0.506)	(3.191)
Start date	-0.505***	-0.229*	-1.126***
	(0.184)	(0.131)	(0.398)
Constant	1.012***	459.6*	2.254
	(370.7)	(265.1)	(1.815)
Observations / pseudo-R2		1,261 / 0.193	

Standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

5.4.3. Openness

Openness of participation is composed of the variables *number* and *diversity*. We define *diversity* as the number of unique public participants (by SBI-code) relative to all participants in a project. To reiterate, Hypotheses 2a and 2b state that mission-oriented projects have a higher number, and greater diversity, of public participants than non-mission-oriented projects. Table 5-5 shows estimations with respect to *number* (models 1-3), and *diversity* (models 4-6). The first model of each batch (models 1 and 4) comprises the controls only, the second model (models 2 and 5) the independent variable only, and the last model (models 3 and 6) all variables.

With the number of public participants in a project as the dependent variable, models 1-3 show that mission themes Energy Transition & Sustainability, Agriculture, Water & Food, and Security significantly predict *number*, supporting Hypothesis 2a. The overall picture regarding *diversity* is quite different. The full model shows that only Agriculture, Water & Food is a significant predictor of *diversity*. This shows that mission-oriented projects are not structurally different from non-mission projects in terms of *diversity*, rejecting Hypothesis 2b.

Table 5-5: Openness: Regression results regarding the constituents.

	(1)	(2)	(3)	(4)	(5)	(6)
Variables	Negative binomial regression Dependent variable: **number**			Fractional logistic regression Dependent variable: **diversity**		
Mission						
1. No mission		0 (base)	0 (base)		0 (base)	0 (base)
2. Energy Transition & Sustainability		1.769***	1.320***		0.860**	0.896*
		(0.309)	(0.381)		(0.402)	(0.476)
3. Agriculture, Water & Food		2.460***	1.521***		1.531***	1.239**
		(0.310)	(0.429)		(0.393)	(0.500)
4. Health & Healthcare		1.505***	0.521		0.865**	0.220
		(0.302)	(0.488)		(0.395)	(0.527)
5. Security		1.469**	1.316**		0.647	1.062
		(0.641)	(0.663)		(0.691)	(0.673)
6. Insufficient information		1.504***	0.885*		1.121**	1.190**
		(0.424)	(0.487)		(0.546)	(0.532)
TKI						
Agriculture & Food (1)	0 (base)		0 (base)	0 (base)		0 (base)
Biobased Economy (2)	-0.207		-0.135	-0.642		-0.642
	(0.694)		(0.726)	(0.778)		(0.776)
Chemical Engineering (3)	-2.033**		-1.713**	-1.388		-1.040
	(0.817)		(0.847)	(0.917)		(0.911)
Creative Industry (4)	0.334		1.483**	1.857***		2.774***
	(0.630)		(0.716)	(0.635)		(0.642)
Delta Technology (5)	1.415***		1.297***	1.173***		1.027**
	(0.424)		(0.429)	(0.415)		(0.416)
Energy (6)	0.344		0.475	0.495		0.585
	(0.435)		(0.491)	(0.442)		(0.471)
High Tech Systems & Materials (7)	-1.297***		-0.633	-0.998**		-0.377
	(0.450)		(0.503)	(0.474)		(0.552)
Logistics (8)	0.297		1.100*	0.415		1.204**
	(0.396)		(0.563)	(0.398)		(0.500)
Life Science & Health (9)	0.522		1.110*	0.158		0.654
	(0.553)		(0.621)	(0.505)		(0.581)
Maritime (10)	-1.219**		-0.569	-1.299*		-0.878
	(0.601)		(0.652)	(0.726)		(0.772)
Horticulture & Vegetative Propagation (11)	1.339***		1.239***	0.945**		0.775
	(0.473)		(0.477)	(0.467)		(0.475)
Water Technology (12)	1.538***		1.546***	1.157***		1.143***
	(0.432)		(0.456)	(0.430)		(0.429)
Start date	-0.259***		-0.321***	-0.191*		-0.219**
	(0.0944)		(0.0975)	(0.104)		(0.104)
Constant	520.1***	-2.951***	645.6***	382.7*	-4.062***	437.1**
	(190.5)	(0.269)	(196.7)	(209.5)	(0.369)	(209.2)
Observations	1,261	1,261	1,261	1,261	1,261	1,261

Standard errors in parentheses.

*** p<0.01, ** p<0.05, * p<0.1

5.4.4. Quality

We operationalise *quality* as the total public investment divided by the total investment in a project. Since this quality measure is a proportion that takes values in the unit interval (i.e. 0 and 1), we use a fractional logit regression to estimate the results. Model 1 in Table 5-6 contains the independent variable *missio*n only, model 2 contains the controls only, and model 3 represents the full model. In model 1, all coefficients are significant, except the mission Security. Controlling for *start date* and *TKI* in model 3 changes this picture. The significance disappears in model 3 after adding the control variables *TKI* and *start date*. Mission categories 3 and 5 are now statistically significant. Comparing models 2 and 3, it is evident however that the addition of *mission* to the controls does not improve the fit of the model in any substantive way.

Table 5-6: Quality: results from a fractional logistic regression.

		(1)	(2)	(3)
		Fractional logistic regression		
Variables		Dependent variable: **quality**		
Mission				
1. No mission		0		0
		(base)		(base)
2. Energy Transition & Sustainability		0.935**		0.970*
		(0.468)		(0.557)
3. Agriculture, Water & Food		1.754***		1.173**
		(0.461)		(0.582)
4. Health & Healthcare		1.161**		-0.262
		(0.460)		(0.700)
5. Security		1.122		1.820***
		(0.699)		(0.596)
6. Insufficient information		1.111*		1.131*
		(0.636)		(0.653)
TKI	Agriculture & Food (1)		0	0
			(base)	(base)
	Biobased Economy (2)		0.215	0.107
			(0.832)	(0.834)
	Chemical Engineering (3)		-1.158	-0.908
			(0.976)	(0.980)
	Creative Industry (4)		2.240***	3.118***
			(0.734)	(0.748)
	Delta Technology (5)		1.893***	1.684***
			(0.505)	(0.505)
	Energy (6)		0.464	0.419
			(0.574)	(0.596)
	High Tech Systems & Materials (7)		-0.771	-0.331
			(0.576)	(0.678)
	Logistics (8)		1.143**	2.285***
			(0.489)	(0.618)
	Life Science & Health (9)		-0.112	0.0901
			(0.639)	(0.678)
	Maritime (10)		-1.758**	-1.474*
			(0.715)	(0.760)
	Horticulture & Vegetative Propagation (11)		1.381**	1.185**
			(0.568)	(0.570)
	Water Technology (12)		1.833***	1.731***
			(0.511)	(0.529)
Start date			-0.333***	-0.358***
			(0.112)	(0.113)
Constant		668.5***	-4.223***	717.0***
		(225.9)	(0.435)	(228.6)
Pseudo R2		0.031	0.110	0.120
Observations		1,261	1,261	1,261

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

The point estimates of the fractional logistic regression are not directly interpretable (Ai and Norton, 2003). Table 5-7 shows predictive margins for the third model (calculated with Stata's *margins* command), and Table 5-8 shows average marginal effects compared to the base category (category 1 no mission). The marginal effects (dy/dx) is the change in *quality* over the base category (mission category 1 in Table 5-7) in percentage points.

Table 5-7 shows that all mission-oriented projects have higher predictions for *quality* than non-mission projects. The base, 'no mission', has a predicted conditional mean of quality of 3 percent, meaning that, on average, total public investments have a share of 3 percent in total investments. Security has the highest predicted conditional mean of 13.9 percent, an improvement of 10.9 percentage points over the base category. However, the confidence intervals of the average marginal effects in Table 5-8 indicate several themes to reach below zero, showing that the association between mission-orientation and *quality* is subject to uncertainty. Hence, we find limited support for Hypothesis 3 that public participants have more influence in mission-oriented than in non-mission-oriented R&I projects.

Table 5-7: Quality: predicted margins.

Mission	Margin	Delta method standard error	z	P>|z|	[95% conf. Interval]	
1. No mission	0.030	0.016	1.85	0.064	-0.002	0.061
2. Energy Transition & Sustainability	0.071	0.022	3.15	0.002	0.027	0.114
3. Agriculture, Water & Food	0.084	0.022	3.80	0.000	0.041	0.127
4. Health & Healthcare	0.023	0.005	5.02	0.000	0.014	0.032
5. Security	0.139	0.061	2.28	0.023	0.019	0.258
6. Insufficient information	0.081	0.033	2.42	0.016	0.015	0.146

Table 5-8: Quality: average marginal effects.

Mission	dy/dx	Delta method Standard error	z	P>|z|	[95% conf. interval]	
1. No mission	(base)					
2. Energy Transition & Sustainability	0.041	0.022	1.86	0.063	-0.002	0.084
3. Agriculture, Water & Food	0.054	0.024	2.29	0.022	0.008	0.100
4. Health & Healthcare	-0.006	0.018	-0.35	0.727	-0.043	0.030
5. Security	0.109	0.055	1.98	0.047	0.001	0.217
6. Insufficient information	0.051	0.033	1.55	0.120	-0.013	0.116

5.5. Discussion and Conclusion

This paper quantitatively examined whether mission-oriented innovation projects are associated with earlier (*intensity*), more open (*openness*), and more influential (*quality*) public participation than non-mission-oriented projects. This section briefly discusses the findings, after which it elaborates on the implications and future research.

5.5.1. Findings

Our results suggest that mission-oriented projects are not always associated with earlier, more open, and more influential public participation than conventional projects. However, the mission theme appears decisive in this regard.

When specifically considering *intensity* we find that various themes – in particular Agriculture, Water & Food – predict upstream and midstream participation, in contrast to downstream participation. Only the mission theme Security does not correlate significantly with earlier participation. We speculate that this may be subject to (one of) the following two explanations: (1) the confidentiality associated with security issues may impede the involvement of the public, and (2) the relatively small sample size of projects that fall within Security may have influenced the results.

Findings in relation to *openness* show that the mission theme Agriculture, Water & Food is also associated with more open projects, both in terms of their number and diversity of public participants. Notably, this theme fosters openness even when highly related TKIs such as Delta Technology and Water Technology do as well. The number of public participants in Energy Transition & Sustainability and Security is likewise greater than in conventional projects. Except for Agriculture, Water & Food, no other theme explains the diversity of public participation.

Compared to non-mission-oriented projects, the *quality* of participation (i.e. the relative economic influence of the public) is the highest for mission-oriented projects linked to Agriculture, Water & Food, and Security. Energy Transition & Sustainability and Health & Healthcare do not predict the quality of public participation.

Because participation appears to depend on the specific mission theme, the hypothesised relationships are obscured at the aggregate level. When comparing missions, it appears that the theme Agriculture, Water & Food is characterised most by public participation. This could be due to the important role of environmental agencies, governmental bodies, NGOs, and civil society organisations in realizing more resilient deltas and sustainable food systems. The mission theme Health & Healthcare did not predict public participation. In practice, the public may be involved in lower degrees of engagement such as co-design and citizen science. These lower engagement approaches are linked to inferior information flows (Arnstein, 1969; Hurlbert and Gupta, 2015), and may lower the responsiveness of projects to inclusive, anticipatory, and reflexive insights (Stilgoe et al., 2013).

Furthermore, one of the findings that stand out is the potential influence some TKIs have on the projects' participatory performance. We find that TKIs such as Creative Industry, Delta Technology, and Water Technology are consistently linked to earlier, more open, and more influential public participation than Agriculture & Food (the TKI baseline). Similarly, Horticulture & Vegetative Propagation and Logistics also correlate positively with multiple participatory indicators. We see two possible reasons why some TKIs positively influence public participation. First, some of these intermediaries have an important brokerage role in network formation and bringing parties together (De Silva et al., 2018; Howells, 2006). Our results indicate that for several TKIs, this is likewise the case for the involvement of public parties. Second, various TKIs relate to particular domains (e.g. creative industry) that may be more proximate to the public. These TKIs could be more dependent on the public for market validation or support, and may therefore encourage participation. This would explain why TKIs such as Chemical Engineering, Maritime, and High Tech Systems & Materials – those less dependent on public validation and support – are not associated with increased public participation.

A last noteworthy finding is that the *start date* of projects has a negative relationship with all dependent variables except for midstream participation. Indeed, missions evolve over time (Wanzenböck et al., 2020). Our results show that the more recent Dutch mission-oriented projects are less inclined to involve the public, suggesting that the 2019 effectuation of policies supporting the turn towards mission-oriented projects has backfired with respect to encouraging public participation. At this point, it is unclear whether this observation is specifically characteristic for the MTIP (including its particular policy priorities and instruments) or whether resorting to university-industry-dominated project teams is just an initial response to any change in the national policy strategy.

5.5.2. Theoretical contributions and policy implications

This paper contributes to theory and practice in various ways. It helps actors understand what to expect from a mission's participatory performance and thus contributes to debates on mission-oriented innovation policy (Foray et al., 2012; Mazzucato, 2017), public participation (Rowe and Frewer, 2005, 2000), and in a broader sense the literature on challenge-led innovation policy (Haddad et al., 2022; Schot and Steinmueller, 2018) and responsible innovation (Stilgoe et al., 2013; Wiarda et al., 2021).

Scholars and policymakers frequently frame missions as promising policy instruments to unite actors towards a shared direction (Edler and Fagerberg, 2017; Mowery et al., 2010; Robinson and Mazzucato, 2019). However, this study finds that the mobilisation of public actors is not self-evident and therefore prompts caution. Whether a mission-orientation encourages public participation through full control, delegated power, or influence through partnerships – i.e. what Arnstein (1969) called 'higher degrees of power' – is predominantly determined by the mission theme. The constellation of missions that fall under these themes seems to stimulate earlier (upstream and midstream) and, in many cases, more (number) public participation. However, these missions tend to lack a diversity of public participants, and the influence they can exert seems limited in light of their relative economic resources.

While missions aim to address societal challenges that tend to affect society as a whole, the limited diversity in their projects may result in neglecting certain values and worldviews that are nevertheless crucial for the effectiveness and desirability of mission outcomes. As Wanzenböck et al. (2020) point out, agreeing on what problems/resolutions efforts should be directed, requires diverse input of heterogeneous stakeholders with the aim of lowering contestation and fostering collective action. Policymakers can increase this missions' diversity by co-creating and framing them more inclusively, making them resonate with a larger spectrum of stakeholders.

Furthermore, the public's limited economic influence hints that the extent to which R&I is directed and shaped according to public values and worldviews presumably depends on the willingness of conventional actors. The public's lack of financial resources may require targeted funding. However, increasing other forms of influence likely requires policymakers to go beyond mere financial instruments and, for instance, pay specific attention to politics and power imbalances (Van Oudheusden, 2014).

While missions are linked to an increased number of public participants, we find that this is not accompanied with an increased diversity of public participants. This is problematic because resolving wicked problems necessitates learning from diverse and conflicting worldviews (Cuppen, 2012; Schot and Steinmueller, 2018). Missions that fail to mobilise a broad range of publics risk overlooking the input of those actors affected by societal challenges, and those related to the resolution's implementation

(Wanzenböck and Frenken, 2020). They moreover jeopardize overlooking the variety of concerns (Latour, 2004) and emotions (Roeser, 2012) that emerge from value conflicts (Smith, 2003). This may give rise to the false impression that ideas about problems and required resolutions are widely shared (Wanzenböck et al., 2020). By extension, missions may risk reflexivity failures (Weber and Rohracher, 2012) as they struggle more than others to cope with the inherent complexity, uncertainty, and contestation linked to their wicked problems of interest (Head, 2008). This is expected to particularly be problematic for so called 'transformer' missions, which provoke more contestation than more technology-oriented 'accelerator' missions (Fisher et al., 2018).

Our study indicates that intermediaries can enhance missions' public participatory performances. While it is widely acknowledged that innovation intermediaries have a brokerage role between two or more parties (De Silva et al., 2018; Howells, 2006), we present empirical evidence that for some intermediaries this is also the case between conventional parties and the public. In our study, this especially holds for those linked to the Creative Industry, Delta Technology, and Water Technology. In some cases deploying intermediaries can be a promising policy instrument to mobilise the public.

Although this paper has not examined this empirically, it is expected that inclusive mission arenas give rise to fundamental disagreement and conflict (Wanzenböck et al., 2020; Wesseling and Meijerhof, 2021). Policymakers, intermediaries, and project teams will have to navigate these through, for instance, constructive or agonistic approaches that enhance mutual learning, avoid stand-stills, and prompt legitimate ways forward (Popa et al., 2021).

5.5.3. Limitations and future research

We present some initial evidence on the extent to which missions mobilise actors and reveal substantial differences in their ability to do so for the public. Although we provide possible explanations for why this may be the case, future research is needed to validate these speculations. Likewise, more research is required to better understand why certain innovation intermediaries are better at including the public than others.

It is important to stress a few limitations of this study. First, the definitions and operationalisations used in this study affect the results. As mentioned, there is no consensus on how to measure public participation. We recognise that this can be done in various ways, and we would like to emphasise that our approach is not the only valid one. Second, we have selected the Netherlands as our empirical environment.

Yet, it is unclear whether our findings can be generalised to other regions. Future research could validate whether this is the case.

Moving forward, several other avenues stand out for future studies. Research could explore to what extent the public engages with missions in lower degrees of power (Arnstein, 1969) through for instance advisory committees, focus groups, or consensus conferences (Rowe and Frewer, 2000). These engagement forms focus on consulting and informing the public (Rowe and Frewer, 2005) and therefore contribute differently to missions than formal participation. Lower degrees of power were unfortunately not reflected in our dataset.

Moreover, we yield insight regarding the participatory performance of funded projects that find themselves in Technology Readiness Level 1-8. To further understand the participatory nature of MIPs throughout their life cycle, future research could examine the public's involvement before projects are funded, i.e. public participation in mission creation and project funding. In addition, a longitudinal analysis could complement our cross-sectional analysis by examining the temporal character of public participation in mission-oriented projects.

Furthermore, we need to better understand *how* the public contributes to mission-oriented projects, especially in light of the limited diversity and influence of the public. This likely requires specific attention to the politics of deliberation (Van Oudheusden, 2014).

Lastly, we lack an understanding of whether public participation can materialise the (implicit) instrumental and substantive promises that are made vis-à-vis missions. In other words, does public participation lead to more rewarding and successful mission outcomes? And what are the potential downsides of public participation? Researching this will contribute to a better understanding of what forms of public mobilization are desirable for missions.

6. Operationalizing Contested Problem-Solution Spaces: The Case of Dutch Circular Construction[16]

6.1. Introduction

Decision-makers are increasingly struggling with challenges that affect society and the environment (Schot and Steinmueller, 2018). These challenges frequently fall into the category of *wicked problems* because they are characterized by inherent complexity and uncertainty, which contribute to their contested nature (Head, 2008; Rittel and Webber, 1973). More specifically, contestation arises as actors embody fundamentally conflicting ideas about the nature of the problems and their required solutions (Head, 2019; Kuhlmann and Rip, 2018). Wanzenböck et al. (2020) introduced the *problem-solution space* as a theoretical framework to conceptualize the extent to which views on these problems and solutions are divergent (i.e., contested). In this increasingly popular framework, views on problems and solutions exist, unfold, and interact and may diverge or converge over time.

Divergent ideas about problems and solutions cause actors to have radically different imaginaries of (un)desirable futures. Imaginaries are intersubjective insofar that actors may (implicitly) share visions once constructed around similar values and worldviews (Jasanoff and Kim, 2015). Contestation thus emerges when different groups hold contradicting imaginaries (Hess, 2015; Kim, 2015). Contestation represents a significant challenge for decision-makers because neglecting or misunderstanding disagreement can further problematize wickedness by prompting standstills, exacerbating conflict, or creating new problems. Decision-makers do not "always 'know best' or 'act best' in understanding problems and proposed solutions" (Kirchherr et al., 2023, p. 4). They are therefore in need of novel approaches for collective sensemaking to mitigate the risk of reflexivity failures (Garud and Gehman, 2012; Weber and Rohracher, 2012).

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Although the problem-solution space offers an important conceptualization of the (divergence of) imaginaries surrounding problems and solutions, there is an explicit demand for the framework's operationalization (Wanzenböck et al., 2020). In the absence of this operationalization, decision-makers inadequately understand what divergent imaginaries exist, how these relate to each other, and how these are distributed among actors. Without an operationalization, decision-makers are insufficiently informed about the extent to which challenges are contested and how this contestation can be navigated. As a result, they could overlook or excluded viable problem understandings and solution pathways (Wesseling and Meijerhof, 2021).

This paper contributes to the reflexive governance of transitions (Voß and Bornemann, 2011) by demonstrating how the contestation dimension of the problem-solution space can be operationalized. It does so by illustrating how divergent imaginaries about problems and solutions can be identified, described, and compared using Q-methodology to better understand the way and extent to which challenges are contested. Q-methodology is a widely adopted research method that helps understand the heterogeneity of intersubjective perspectives (Brown, 1982; Stephenson, 1935). By revealing opposing imaginaries, our paper demonstrates how decision-makers (e.g., policymakers) can reflexively learn about alternative understandings of the problem-solution space of a given societal challenge (Feindt and Weiland, 2018). Continuously reflecting on the directionality of transformations allows for more tentative forms of governance that are more responsive to stakeholder worldviews despite interpretive flexibility (Bijker, 1987; Kuhlmann et al., 2019; Stilgoe et al., 2013).

To demonstrate this approach, we use the case of the Dutch circular construction in which the government has set out a contested imaginary, that we call *'Circular construction by 2050'*, and which is being implemented through policies (Coenen et al., 2022a). Our paper therefore also provides case specific insights that could help policymakers align imaginaries for more collective responses.

In what follows, this paper first elaborates on its theoretical background (Section 6.2), followed by an explanation of the paper's methodology (Section 6.3). This section also introduces and justifies the case that is chosen for the paper. Section 6.4 proceeds by describing the identified imaginaries after which Section 6.5 compares these to understand the contestation (Section 6.5). The paper concludes by discussing different ways contestation could be navigated, and by reflecting on the paper's contribution (Section 6.6).

6.2. Wicked Problem-Solution Spaces and Contested Imaginaries

6.2.1. Problem-solution spaces

Due to the enduring nature of wicked problems, solutions to these problems are deemed provisional, while the problems themselves are never solved. Provisional solutions strive to unfold "a never-ending discourse with reality, to discover yet more facets, more dimensions of action, more opportunities for improvement" (Dery, 1984, pp. 6–7). Wicked problems do therefore not have a 'stopping rule' (Rittel and Webber, 1973). Rather than 'solving' these problems, scholars speak of 'resolving', 'coping with', and 'managing' wickedness (Head and Xiang, 2016; Xiang, 2013).

The problem-solution space underlines this tentative and wicked nature of problems and solutions. Wanzenböck et al. (2020) provided various illustrative case studies to show that views on problems and solutions may diverge or converge (Figure 6-1). There are, for example, increasingly more convergent views on the problem of obesity while there is widespread disagreement on which of the numerous interventions are needed to tackle this. Self-driving cars contrarily suggests that disagreement may also emerge on what problems some concrete innovations can resolve. While problems and solutions are open to dissimilar levels of contestation, developments around smoking bans, wind energy, and CCTV demonstrate how problem-oriented and solution-oriented views can both converge over time.

Next to the convergence of problem and solution framings, framings may interact in the sense that the framing of one suggests the framing of the other (Bacchi, 2009; Ison et al., 2014; Peters, 2005). For instance, the reduction of CO_2 emissions as a solution for climate change hints that CO_2 emissions are (part of) the problem.

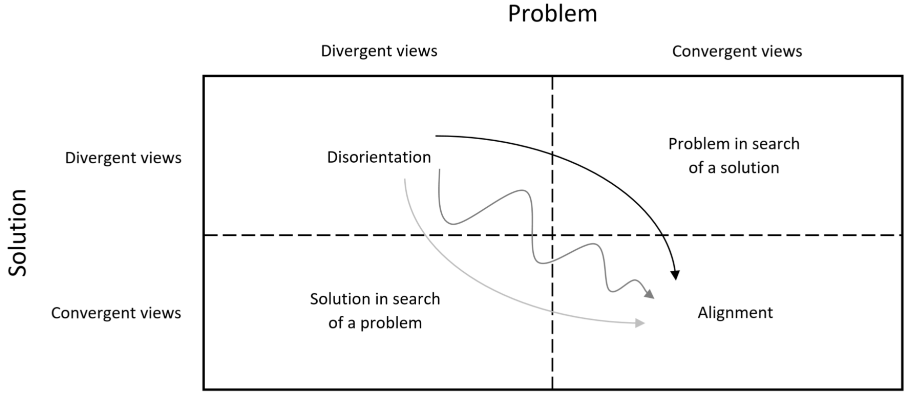

Figure 6-1: The problem-solution space. Source: Wanzenböck et al. (2020)

More fundamentally, problems are contested because they can be framed as symptoms of higher-level problems and can be explained in numerous ways (Rittel and Webber, 1973). Solutions are contested as stakeholders embody radically different, or even conflicting, values and worldviews – solutions that meet one's preferences may displease those of others (Dentoni and Bitzer, 2015; Pesch and Vermaas, 2020). The number of possible solutions is also non-exhaustive, and they are often impossible to test because it would change existing problems or create new ones (Rittel and Webber, 1973). As such, contestation often relates to the epistemic nature of problems, and the risks, uncertainties, and opportunities associated with potential solutions (e.g., Dignum et al., 2016; Ligtvoet et al., 2016). Sources of contestation are moreover exacerbated by the complexity and uncertainty associated with wickedness (Head, 2019).

Contestation is in many cases a future-oriented phenomenon because possible solutions are usually not yet developed and implemented. While contestation about future scenarios can relate to predictions (i.e., what *will* happen) and explorations (i.e., what *could* happen), it nearly always involves normative ideas (i.e., what *should* happen; Börjesona et al., 2006; Ligtvoet et al., 2016). These visions may be made explicit through the act of framing. Visions for (un)desirable futures tend to be collectively held even though only a selective group of actors actively partakes in the political discourse that emerges from explicit framings (Konrad and Böhle, 2019). Framings thus explicate only a fraction of collectively held visions in society even though nearly all visions have a performative function. As a result, disagreement is often obscured, undisclosed, and latent. An analytical shift from framings to collectively-held visions is therefore helpful in revealing and understanding contestation.

6.2.2. Imaginaries

Jasanoff and Kim (2015) refer to these collectively-held visions as s*ocio-technical imaginaries*, which they defined as: "collectively held, institutionally stabilized, and publicly performed vision[s] of desirable futures, animated by shared understandings of forms of social life and social order attainable through, and supportive of, advances in science and technology."(p.5). As such, imaginaries represent normative socio-technical visions that are held by a group of individuals and which are publicly performed (Sovacool et al., 2019). Attaining these desirable futures through science and technology suggests that imaginaries contain a strong solution-oriented view that is constructed on present-day problems. Jasanoff and Kim (2015) argued that imaginaries can be utopian or dystopian, hinting that imaginaries do not necessarily emphasise problems and solutions equally.

Imaginaries are co-constructed and enable individuals to be connected by shared narratives, norms, and discourses, without having ever met. They are thus social constructs (Bijker, 1987) that implicitly or explicitly reflect matters of concern (Latour, 2004). They lay at the nexus of how society co-produces epistemic and normative understandings of the world, i.e., how things are and how things should be (Jasanoff, 2004). Imaginaries thus have a performative function as they shape the future by steering practices in the present (Delina, 2018). Imaginaries are inherently political (Granjou et al., 2017; Konrad and Böhle, 2019; Marquardt and Delina, 2019) because they inscribe a "vision of (or prediction about) the world" (Akrich, 1992, p. 208) that imposes particular values and worldviews (Winner, 1980). Inspired by Haraway, (1991, 1988), it may therefore be fitting to speak of 'situated' imaginaries as they reflect the values and worldviews of the 'imaginator'.

Indeed, governmental imaginaries that are publicly performed through policies (e.g. missions and strategies) "are associated with exercises of state power" (Jasanoff and Kim, 2009, p. 123) and tend to spark contestation (Hermann et al., 2022; Sismondo, 2020). Yet, imaginaries are not merely held by authorities such as experts and governments, but are also created, held, and reconfigured by other types of actors (Smith and Tidwell, 2016). As a result, problem-solution spaces are associated with a constellation of different imaginaries that are held by a broad range of groups. These imaginaries exist in parallel, co-evolve, and constitute what Burnham et al. (2017) call the 'politics of imaginaries'. In this political landscape, divergent views on problems and solutions are reflected by the existence of multiple imaginaries that generally clash (Hess, 2015; Levidow and Raman, 2020; Marquardt and Delina, 2019).

In this paper, we operationalize the notion of problem-solution spaces as the plurality of contradicting, often undisclosed, imaginaries that shape conflict and practices in the present. Revealing what futures should (not) look like according to different stakeholder is a crucial reflexive exercise needed to learn from disagreement (Cuppen, 2012; Ligtvoet et al., 2016). Reflexivity can therefore play an important role in the alignment of imaginaries (Figure 6-1). For instance, governments could subsequently reformulate policies in a way that they resonate with the perceived problems and desirable solutions of other imaginaries (Huang and Westman, 2021). In what follows, this paper discusses the case and method used to identify and describe conflicting imaginaries in problem-solution spaces.

6.3. Methodology

This study aims to identify, describe, and compare divergent imaginaries as an operationalization of contestation in the problem-solution space. In what follows, we first introduce and justify our selected case study (Section 6.3.1.), and then explain how and why Q-methodology can be used to identify the imaginaries of its problem-solution space.

6.3.1. The case of Dutch circular construction: *'Circular construction by 2050'*

We selected the empirical context of the government-led mission *'Circular construction by 2050'*. This case was selected for a variety of reasons. First, this circularity mission is broadly recognized to be highly contested in terms of both its problem and solution-space (Coenen et al., 2022a). The wickedness associated with circular economy is reflected by heated debates among actors. For instance, practitioners question whether circular economy could even address environmental concerns and some believe it may have become a goal in itself (Calisto Friant et al., 2020; Corvellec et al., 2022). These divergent views on problems and solutions indicate that *'Circular construction by 2050'* does not fall into the 'alignment' quadrant of the problem-solution space (Figure 6-1). Moreover, its institutionally fragmented character and the sector's dependency on public funds is believed to invite hostility between public and private parties. Second, the construction sector is relevant because its large use of natural resources and waste creation suggest that a transition to circularity can have a major impact on society and the environment (Ghaffar et al., 2020). Third, although the Dutch circular construction sector is a frontrunner in the domains of waste management and reuse innovations, it is still in an early transition phase (Giorgi et al., 2022). Fourth, the Dutch government was one of the first to issue a top-down policy on circular construction. The contested problem-solution space, institutional fragmentation, high stakes, and early transition stage in combination with this top-down approach indicate that various imaginaries presumably coexist with the imaginary *'Circular construction by 2050'* that is articulated through the government-led mission. This provides for a rich empirical setting to operationalize the problem-solution space. The government-led mission and its context are as follows.

In 2016, the Dutch government set out a mission for the Netherlands to be fully circular by 2050 (IenW and EZK, 2016). This mission was divided by the ministry into five priority sectors, including construction. The construction mission includes both building construction and the infrastructure sector, and as such addresses the entire built environment. The imaginary *'Circular construction by 2050'* was accompanied by a circular economy strategy report that introduced three objectives: (1) the high-grade utilization of available resources and waste flows; (2) the substitution of fossil and non-sustainably produced resources by widely available and renewable alternatives; (3) and the rethinking of consumption in conjunction with the reconfiguration of products and production methods. The same strategy report acknowledges that circular economy should be understood as a utopian vision to mobilize actors into a shared direction. It is idealistic in the sense that attaining such a fully 'closed' system is unlikely because of inevitable waste flows.

A transition team was installed for the construction sector that contained both policymakers and representatives of various stakeholder groups, including construction firms, engineering firms, national and regional clients, knowledge organizations, and interest groups. This team issued a strategic agenda that lays out how they believe the construction sector should be transformed into a circular one by 2050 (Transitieteam bouw, 2018). It directs efforts from a policy perspective towards developing a circular market, measuring circularity, establishing and implementing policies and legislation, and enhancing knowledge production and diffusion. In addition, it functions as the main advisory group to the Ministry that is responsible for circular construction.

In 2019, the Transition Team set out annual Implementation Programs which monitored the mission's progress, prioritization, and policy landscape (BZK, 2019). Focus in these strategies shifted increasingly from addressing resource efficiency to a more integral view on environmental sustainability and economic viability, including CO_2 reduction, energy efficiency, and reducing supply risks.

However, many circularity-related efforts in the sector did not align with the strategy presented by the Transition Team. Instead, efforts were often initiated by single actors that act in accordance with their own vision for circular construction (Coenen et al., 2022b). Several of these efforts are now nevertheless considered prominent examples of circularity in the sector. The emergence of these alternative problem framings and the success of alternative solutions (e.g., bio-based materials and the reuse of building components) highlight the contested nature of the Dutch circular construction sector and reinforces the need for a more reflexive governance. However, this observation does not necessarily inform us about what problem-solution imaginaries exist and how they relate to each other.

6.3.2. Identifying imaginaries using Q-methodology

Q-methodology is an approach that helps understand an individual's subjectivity in relation to inter-subjectivity (Brown, 1982; Stephenson, 1935). The method has roots that stretch back to the early 20th century and has been used in numerous fields to identify, describe, and compare views on topics of interest (e.g., Davies and Hodge, 2007; Gruszka, 2017; Rajé, 2007; Wolsink and Breukers, 2010). Scholars recently underlined Q-methodology's potential, but limited uptake, in the context of transitions (Hansmeier et al., 2021). Some transition studies have already used the method to study inter-subjectivity (e.g., perspectives, imagined publics) related to solutions like carbon taxes (Mehleb et al., 2021), electric vehicles (Lee and Park, 2023), resource management (Gruber, 2011; Kügerl et al., 2023; Streit et al., 2023), and biomass/gas (Bauer, 2018; Cuppen et al., 2010; Rodhouse et al., 2021; Silaen et al., 2020).

This paper applies Q-methodology to identify, describe, and compare divergent imaginaries specifically in relation to the problem-solution space. Q-methodology is suitable for this purpose for at least four reasons. First, imaginaries are understood as "collectively held … vision[s] of desirable futures" (Jasanoff and Kim, 2015, p. 5). Q-methodology is specifically designed to derive *collectively held* views from individual ones, and therefore goes beyond alternative research methods like interviews and focus groups. Second, it yields insights into the heterogeneity of these collectively held viewpoints (i.e., the degree of divergence) in contrast to finding the most generalizable viewpoint as commonly done in descriptive statistics. Identifying this heterogeneity is not only crucial for understanding and navigating conflict, but also for the inclusion of minorities' perspectives. Third, it allows the researcher to identify these collectively held views within a debate without predefining groups. The respondents largely determine what shared views emerge from the analysis, reducing researchers' bias (Robbins and Krueger, 2000). Fourth, the collectively held views that emerge from Q-methodology allow for their systematic comparison by using their, so-called, factor arrays – the typical answers for each collectively held view. This systematic comparison contributes to the reproducibility of the approach.

Q-methodology involves six steps that include data collection and data analysis (c.f. Cuppen et al., 2010). The first step concerns taking stock of the 'concourse'. This refers to the wide range of ideas that constitute the topic of interest. In order to identify the variety of views on the problems and solutions vis-a-vis circular construction, this paper adopts data from Coenen et al. (2022a). The data concerns transcripts of approximately 90 minute long semi-structured interviews with 20 stakeholders that relate to the imaginary *'Circular construction by 2050'*. These stakeholders were selected through purposive sampling to cover the heterogeneous institutional roles found in innovation systems as described by Kuhlmann and Arnold (2001), such as industrial actors (e.g., contractors, engineering firms), intermediaries (e.g., network organizations, standardization institutes, consultancies), consumers (e.g., construction clients), societal stakeholders (e.g., civil society organizations, representatives), governmental organizations (e.g., ministries), and research institutes (e.g., research institutes and universities). The transcripts are highly relevant as the interviews aimed to identify stakeholders' perspectives on the Dutch circular construction's problem-solution space. Interviewees were specifically asked what they believed were the problems that circular construction addresses, and what the solutions are that could realize circular construction. Interviews were conducted until no new themes emerged (i.e., thematic saturation). Although interviews are not strictly necessary for a Q-methodology, they were used to enhance the validity of our concourse.

The second step aims to distil a manageable set of diverse statements that reflects the heterogeneity of the concourse – hereafter called the 'Q-set'. Deriving statements was done through inductive thematic analysis (Braun et al., 2019; Braun and Clarke, 2006). Transcripts were analyzed using 'open coding' on the sentence level according to two themes: the *problems* that circular construction aims to address (1), and the *solutions* that could realize circular construction (2). For our coding rules we defined problems as "matters that causes one difficulty or need to be dealt with" and defined solutions as "*answers to* problems". Themes that emerged from 'axial coding' were collectively discussed to resolve any inter-coder disagreements, and were each collectively translated into statements. Statements should be unique, clear, and brief. Overlapping statements were omitted or merged. All statements were shared with three stakeholders (i.e., two researchers and one practitioner) to test them for unambiguity. The thematic analysis resulted in 45 statements of which 18 were problem-oriented and 27 solution-oriented (Appendix E.1.).

The third step involves the selection of respondents – i.e. the P-sample. Because Q-methodology aims to reveal the *variety* of perspectives as opposed to reflecting the relative *importance* of perspectives, Q-methodology is usually done through purposive sampling with small sample sizes, as opposed to random sampling with large sample sizes (McKeown and Thomas, 1988). Typical sample sizes range from 20 – 60 respondents (Phi et al., 2014). Moreover, the diversity of respondents' worldviews is crucial for Q-methodology. Purposive sampling therefore aims to include respondents that reflect the broad range of views on a particular topic. These respondents are usually different from those who were interviewed for the concourse (step 1) to enhance the robustness of Q-methodology. To ensure a diverse P-sample, 58 actors were invited by email to partake in this study, and chosen based on their actor type (e.g., industry) and sub-type (e.g., supplier) that they represent (Appendix E.2.). This resulted in 34 respondents.

The fourth step refers to the Q-sort. During the Q-sort, respondents ranked the statements on a Likert-scale according to their vision i.e., -5 to 5 in which -5 represented 'relatively agree with least' and 5 indicated 'relatively agree with most' (Figure 6-2). Ranking followed a normal distribution with few statements on each extreme. Q-sorts were digitally sorted and collected using qmethodsoftware.com, which is an online survey platform (Lutfallah and Buchanan, 2019). Respondents entered this survey by email invitations. A Pearson correlation matrix of the 34 Q-sorts was created to yield an understanding of the P-sample's diversity. The mean Q-sort correlation is 0.29, suggesting a heterogeneous P-sample in terms of visions for the Dutch circular construction sector.

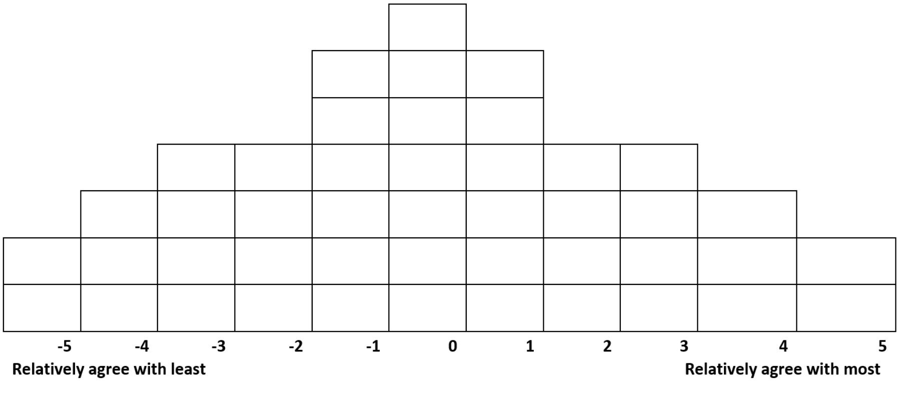

Figure 6-2: Q-sort distribution. Source: authors' own elaboration.

In the fifth step, a factor analysis is conducted to yield groups (i.e. factors) of highly correlating Q-sorts (i.e. rankings). For Q-methodology, the standard approach is a centroid factor analysis with a Varimax factor rotation (Watts and Stenner, 2005). Factors are typically included if they contain at least one *unique* factor loading, indicating that at least one respondent's perspective corresponds best with a factor. Furthermore, factors preferably meet both the Kaiser-Guttman criterion and Humphrey's rule.

In this study, factors that emerge from the analysis represent imaginaries with which multiple respondents' visions correlate. We followed the approach described above and included factors with at least one *unique* factor loading of 0.385 or above, indicating a vision's correlation with a factor at the statistically significant level of $p < 0.01$ (Equation 1). This factor loading threshold was computed as follows (McKeown and Thomas, 1988):

$$Factor\ loading = 2.58 * SE = 2.58 * \frac{1}{\sqrt{N\ statements}} \tag{1}$$

The factor analysis resulted in 3 factors (i.e., imaginaries), with which the visions of 30 respondents correlated significantly (Appendix E.2.). It must be noted that a respondent's vision can correlate significantly with multiple factors. To enhance the comprehensibility of the results, we grouped every respondent with the factor that the person correlated best with. 4 respondents did not load significantly on any factor. All factors satisfied both the Kaiser-Guttman criterion and Humphrey's rule. Appendix E.3. and Appendix E.4. provide the factor arrays and factor loadings, respectively.

In the sixth step, these factors are interpreted using several forms of data. The interpretation is largely based on the highest/lowest (+5,+4,-4,-5) and distinguishing statements (Table 6-1, 6-2, and 6-3). Distinguishing statements are those that were Q-sorted differently, on the statistically significant level of $p < 0.01$, for one factor in comparison to remaining factors (Coogan and Herrington, 2011; Rodhouse et al., 2021). The nature of statements that followed from step two furthermore inform us about the orientation of factors (i.e. problem-oriented or solution-oriented). We also used the preliminary interview data to contextualize the factors and statement scores. Each factor represents an imaginary regarding the Dutch circular construction sector.

The analysis was extended by comparing these identified imaginaries with the government-constructed imaginary *'Circular construction by 2050'* (Section 6.3.1.) as presented through various policy documents (e.g., BZK, 2019; IenW and EZK, 2016). These policy documents were subject to the same thematic analysis, as described in step two of this section, to understand the explicitly mentioned problem-oriented and solution-oriented views of the government.

6.4. Results

In what follows, Section 6.4 describes each imaginary that emerged from the Q-analysis. We have named these three imaginaries *'We need to use less resources more* *efficiently'* (Section 6.4.1), *'Let's reimagine design strategies'* (Section 6.4.2), and *'Construction needs a mix of solutions'* (Section 6.4.3).

6.4.1. Imaginary 1: *'We need to use less resources more efficiently'*

Respondents that support this imaginary appear to have a defined idea of the problem (Table 6-1). Circular construction can help avoid resource depletion and contribute to a climate-neutral society. This imaginary disagrees most with the statements that circular construction will reduce the risk of water shortages, and will benefit the water quality in the Netherlands. This imaginary unanimously agreed on the insignificancy of circularity for social inequalities. In terms of solutions, it believes that circularity should be achieved through a reduction of primary resources. The actors unanimously agreed on the importance of using resources more efficiently. In addition, this imaginary supports a cradle-to-cradle approach and the minimization of material use. They furthermore doubt that block chain or a change in asset ownership would effectively resolve the problems circular construction aims to address.

17 respondents correlated significantly with this imaginary, of which 13 corresponded best with it. 7 respondents correlated solely on this imaginary. The 13 respondents consisted of actors from the category industry (N=2), construction clients (N=4), researchers (N=4), advisory firms (N=2), and infrastructure (N=1).

Table 6-1: Distinguishing (D) and most defining (+5,+4,-4,-5) problem-oriented (P) and solution-oriented (S) statements.

Distinguishing and defining statements	No.	Statement
+5	5(P)	With circular construction, we avoid the depletion of our earth
+5 (D)	17(P)	Circular construction contributes to achieving a climate-neutral society
+4	23(S)	A reduction in the use of primary resources must be a priority for circular construction
+4	27(S)	Circular construction starts with thinking about how to use resources efficiently
+4 (D)	41(S)	Circular construction will need to focus more on the 'cradle-to-cradle' strategy
+3 (D)	37(S)	In circular initiatives, more focus is needed on sustainable materials
+2 (D)	32(S)	Future circular projects should focus on avoiding material use as much as possible
0 (D)	34(S)	Circular construction requires that assets are designed for disassembly
0 (D)	4(P)	Circular construction addresses the problem of waste production
0 (D)	6(P)	The problem of linear construction lies mainly in the use of primary resources
0 (D)	21(S)	Modular design is essential for circular construction
0 (D)	25(S)	Circular construction requires new monitoring and measurement systems that can be used to manage circularity
-1 (D)	13(P)	Circular construction can reduce the sector's energy consumption
-1 (D)	19(S)	In a circular construction, down cycling of materials is inevitable
-2 (D)	18(P)	Circular construction is primarily a means to reduce greenhouse gas emissions
-2 (D)	35(S)	Material passports are necessary to realize circular construction
-3 (D)	1(P)	Circular construction provides lower particulate emissions than linear construction
-3 (D)	40(S)	Climate adaptive building contributes to achieving circular construction
-3 (D)	30(S)	As-a-service business models play a key role in kick-starting the transition to circular construction
-4	15(P)	Circular construction contributes to reducing social inequalities in our society
-4 (D)	26(S)	In order to realize a circular construction, suppliers and contractors must ultimately become responsible for assets over their entire life cycle
-4 (D)	42(S)	Block chain can play an important role in making circular construction a reality
-5	8(P)	Circular construction reduces the risk of water shortages in the Netherlands
-5	11(P)	Circular construction benefits the water quality of the Netherlands

6.4.2. Imaginary 2: *'Let's reimagine design strategies'*

Imaginary 2 believes that circular construction helps address resource depletion and achieve a climate-neutral society, and comparatively disagrees that circular construction will combat water shortages, water pollution, social inequalities, and biodiversity loss (Table 6-2). It appears to fairly disagree that circular construction can and should prioritize waste reduction. In terms of solutions, this imaginary primarily focuses on design strategies. While this group believes downcycling is avoidable, it is not a proponent of recycling as a solution pathway. Instead, design strategies should strive to move material flows as high as possible on the R-ladder (e.g., refuse, rethink, reuse, etc.). Although resource efficiency is deemed important, circular construction should also focus on modular designs and design-for-disassembly. The imaginary pleads for material passports, and new monitoring and measurement systems to provide insight into circularity.

13 respondents correlated significantly, of which 9 corresponded best with this imaginary. 6 respondents correlated solely on this imaginary. The 9 respondents consisted of actors from the category industry (N=1), construction clients (N=3), policy (N=1), researchers (N=2), advisory firms (N=1), and infrastructure (N=1).

Table 6-2: Distinguishing (D) and most defining (+5,+4,-4,-5) problem-oriented (P) and solution-oriented (S) statements.

Distinguishing and defining statements	No.	Statement
+5 (D)	28(S)	Material and design strategies should focus on the highest possible R-strategy on the "R-ladder"
+5	5(P)	With circular construction, we avoid the depletion of our earth
+4	27(S)	Circular construction starts with thinking about how to use resources efficiently
+4	21(S)	Modular design is essential for circular construction
+4	34(S)	Circular construction requires that assets are designed for disassembly
+3 (D)	25(S)	Circular construction requires new monitoring and measurement systems that can be used to manage circularity
+3 (D)	17(P)	Circular construction contributes to achieving a climate-neutral society
+2 (D)	35(S)	Material passports are necessary to realize circular construction
+1 (D)	23(S)	A reduction in the use of primary resources must be a priority for circular construction
0 (D)	39(S)	Circular construction requires substantial changes in current laws and regulations
0 (D)	18(P)	Circular construction is primarily a means to reduce greenhouse gas emissions
-1 (D)	36(S)	New standards and guidelines are needed to facilitate circular construction
-1 (D)	1(P)	Circular construction provides lower particulate emissions than linear construction
-2 (D)	26(S)	In order to realize a circular construction, suppliers and contractors must ultimately become responsible for assets over their entire life cycle
-2 (D)	6(P)	The problem of linear construction lies mainly in the use of primary resources
-3 (D)	8(P)	Circular construction reduces the risk of water shortages in the Netherlands
-3 (D)	33(S)	Circular construction should focus on reducing waste production
-3 (D)	7(P)	Circular construction is necessary to combat the decline of biodiversity
-4	11(P)	Circular construction benefits the water quality of the Netherlands
-4	15(P)	Circular construction contributes to reducing social inequalities in our society
-4 (D)	4(P)	Circular construction addresses the problem of waste production
-5 (D)	19(S)	In a circular construction, down cycling of materials is inevitable
-5 (D)	22(S)	The construction sector must focus on recycling to become circular

6.4.3. Imaginary 3: *'Construction needs a mix of solutions'*

According to imaginary 3, the central problem that circular construction tackles is the overuse of primary resources to prevent resource depletion (Table 6-3). It relatively disagrees that circular construction could reduce greenhouse gasses and particle emissions. Furthermore, it seems comparatively unconvinced of the potential benefits of circularity in relation to water shortages, water pollution, biodiversity loss, and social inequalities. What sets imaginary 3 apart from other imaginaries is its strong support for a mix of solutions. It advocates material passports, and new monitoring and measurement systems to manage circularity. It also implores changes in procurement strategies and living standards. Imaginary 3 supports novel design strategies such as modular design and design-for-disassembly. A number of these solutions focus on facilitating circularity.

12 respondents correlated significantly, of which 8 corresponded best with this imaginary. 5 respondents correlated solely on this imaginary. The 8 respondents consisted of actors from the category industry (N=1), construction clients (N=5), and advisory firms (N=2). Noteworthy is that nearly half of all actors falling in the category construction clients correlate statistically significantly with this imaginary (6 out of 13).

Table 6-3: Distinguishing (D) and most defining (+5,+4,-4,-5) problem-oriented (P) and solution-oriented (S) statements.

Distinguishing and defining statements	No.	Statement
+5 (D)	25(S)	Circular construction requires new monitoring and measurement systems that can be used to manage circularity
+5	23(S)	A reduction in the use of primary resources must be a priority for circular construction
+4	34(S)	Circular construction requires that assets are designed for disassembly
+4	21(S)	Modular design is essential for circular construction
+4 (D)	44(S)	Procurement strategies are essential tools for achieving circular assets
+3 (D)	35(S)	Material passports are necessary to realize circular construction
+1 (D)	6(P)	The problem of linear construction lies mainly in the use of primary resources
+1 (D)	45(S)	Reducing the material demand requires changes in our lives, for example by living smaller
+1 (D)	16(P)	With circular construction, the industry's supply risks of materials and components can be decreased
-1 (D)	31(S)	A carbon tax is a crucial measure to accelerate the transition to a circular construction sector
-1 (D)	2(P)	One of the goals of circularity in the construction industry is to reduce greenhouse gas emissions
-1 (D)	14(P)	The core problem that circular construction addresses is environmental impact and climate change
-2 (D)	17(P)	Circular construction contributes to achieving a climate-neutral society
-2 (D)	4(P)	Circular construction addresses the problem of waste production
-3 (D)	12(P)	Circular construction can prevent health damage by better handling toxic materials
-3 (D)	19(S)	In a circular construction, down cycling of materials is inevitable
-3 (D)	20(S)	Circular construction requires that a large portion of the materials used be bio-based
-3 (D)	26(S)	In order to realize a circular construction, suppliers and contractors must ultimately become responsible for assets over their entire life cycle
-4	11(P)	Circular construction benefits the water quality of the Netherlands
-4 (D)	1(P)	Circular construction provides lower particulate emissions than linear construction
-4 (D)	18(P)	Circular construction is primarily a means to reduce greenhouse gas emissions
-5	15(P)	Circular construction contributes to reducing social inequalities in our society
-5	8(P)	Circular construction reduces the risk of water shortages in the Netherlands

6.5. Comparing Imaginaries

Section 6.5.1 proceeds by comparing these imaginaries based on their highest/lowest statements to understand contestation. Section 6.5.2 follows by comparing the three identified imaginaries with the government-constructed imaginary *'Circular construction by 2050'*.

6.5.1. Comparing identified imaginaries

This section compares the three imaginaries to understand their differences and similarities. Table 6-4 provides a correlation matrix of the three imaginaries. Both the correlation matrix and the descriptions above suggest room for common ground as they share various normative ideas. For example, all imaginaries agree that circular construction could address the problem of resource depletion of (primary) resources by increasing efficiency. All imaginaries seem to relatively disagree with the idea that asset ownership should be shifted from public organizations to suppliers and contractors. In addition, all imaginaries seem to disagree that circular construction addresses water pollution, water shortages, and social inequalities. Hence, all imaginaries seem skeptical about some potential socio-environmental benefits of circular construction. The mean Likert-scale ranking of the problem-oriented statements and solution-oriented statements (Table 6-5) suggest furthermore that imaginary 3 *'Construction needs a mix of solutions'* agrees more with the solution statements and less with the problem statements than the other imaginaries.

Imaginary 2 *'Let's reimagine design strategies'* and imaginary 3 *'Construction needs a mix of solutions'* are most similar (r = 0.65). Actors from both these groups tend to support modular designs, design-for-disassembly, material passports, and new monitoring and measurements systems. They believe that down cycling is preventable. However, these imaginaries relatively disagree on the importance of circular construction for climate-neutrality. Imaginary 3 furthermore disagrees that circular construction reduces greenhouse gas and particulate emissions. Imaginary 2 also differs from imaginary 3 in the sense that imaginary 3 appears less confident about the problems that circular construction addresses.

Imaginary 1 *'We need to use less resources more efficiently'* and imaginary 2 *'Let's reimagine design strategies'* (r = 0.60) both believe that circular construction will contribute to climate-neutrality, and that it must prioritize efficient resource use. Yet, imaginary 2 seems to be a greater proponent of closed systems while imaginary 1 emphasizes the reduction of material flows.

Imaginary 1 *'We need to use less resources more efficiently'* and imaginary 3 *'Construction needs a mix of solutions'* are the least similar imaginaries (r = 0.57). Both imaginaries relatively disagree with the idea that suppliers and contractors should be responsible for assets throughout their life cycle. These two imaginaries also believe that circular construction will not lower greenhouse gas emissions and particulate emissions. While imaginary 3 predominantly focuses on solutions, imaginary 1 demonstrates a more balanced view, focusing on both problems and solutions. Imaginary 3 supports a plurality of solutions, advocating modular designs, design-for-disassembly, novel procurement strategies, material passports, and new monitoring and measurement systems. Imaginary 1 signifies a more narrow solution space, prioritizing efficient resource use, sustainable material, and cradle-to-cradle strategies.

Lastly, the actor types from our P-sample appear fairly evenly distributed among imaginaries (Table 6-6). The only actor type that is disproportionally distributed are researchers. Most researchers are adherents of the first (N=4) and second imaginary (N=2), but none support the third imaginary (N=0). This suggests that the normative visions of circular construction are largely independent of the actor type.

Table 6-4: Pearson correlation matrix between imaginaries.

	Imaginary 1	**Imaginary 2**	**Imaginary 3**
Imaginary 1	1.00	0.60	0.57
Imaginary 2	0.60	1.00	0.65
Imaginary 3	0.57	0.65	1.00

Table 6-5: Mean ranking of problem-oriented statements and solution-oriented statements per imaginary on a Likert-scale of +5 to -5.

	Mean ranking problem-oriented statements	**Mean ranking solution-oriented statements**
Imaginary 1	-0.61	0.41
Imaginary 2	-0.61	0.41
Imaginary 3	-1.50	1.00

Table 6-6: Number of actors with highest significant loading per imaginary. Note: actors with non-significant loadings are not included.

	Industry	Con-struction clients	Policy	Research-ers	Advisory firms	Infra-struct-ure	Total
Imagin-ary 1	2 (40%)	4 (33%)	0 (0%)	4 (67%)	2 (40%)	1 (50%)	13 (38%)
Imagin-ary 2	1 (20%)	3 (25%)	1 (100%)	2 (33%)	1 (20%)	1 (50%)	9 (26%)
Imagin-ary 3	1 (20%)	5 (42%)	0 (0%)	0 (0%)	2 (40%)	0 (0%)	8 (24%)
Total	5 (100%)	12 (100%)	1 (100%)	6 (100%)	5 (100%)	2 (100%)	30 (100%)

6.5.2. Comparing identified imaginaries with the *'Circular construction by 2050'* imaginary

Our results indicate that the three imaginaries differ in the extent to which they acknowledge and favor certain problems and solutions. These imaginaries coexist with the imaginary '*Circular construction by 2050'* as constructed by the Dutch government, and actualized through its formal policy (BZK, 2019; IenW and EZK, 2016). While it is increasingly recognized that imaginaries may clash (Burnham et al., 2017; Hess, 2015), we identify and describe the problems/solutions that various imaginaries disagree on. We furthermore reveal spaces for common ground that could foster a collective response. These differences and commonalities informs us about how policymakers can possibly move forward.

When focusing on common grounds, all three identified imaginaries seem to agree with the '*Circular construction by 2050'* imaginary that circular construction could address the depletion of (primary) resources by focusing on their efficient use. Similar to the three identified imaginaries, the *'Circular construction by 2050'* imaginary does not target water pollution, water shortages, and social inequality. This opposes several perspectives derived from the concourse interviews (Section 6.3.2, step 1). Especially one interviewee from the Dutch Union of Water boards envisioned that circular construction would result in these benefits. However, our results suggest that this vision is not widely shared. The *'Circular construction by 2050'* furthermore stresses the importance of both material passports, and new measurement and monitoring systems. While this vision resonates with that of imaginary 2 and 3, it is considered less important in imaginary 1.

In terms of contestation, imaginary 1 and 3 both seem skeptical that circular construction will lower greenhouse gas emissions. This fundamentally contradicts the

'Circular construction by 2050' imaginary in which CO_2 reduction forms one of the main rationales for circular construction (BZK, 2019; IenW and EZK, 2016). In addition, a very clear solution priority for imaginary 2 and 3 – and in a lesser extent for imaginary 1 – is the use of modular designs and design-for-disassembly. Yet, this is hardly mentioned by the strategy rapports that delineate the government's imaginary. The *'Circular construction by 2050'* imaginary also pleads for more regulation and standardization of circular construction, but the other imaginaries seem less outspoken about such approaches. The same can be argued for climate adaptive approaches to construction. While the government supports this solution pathway, other imaginaries are less outspoken about it.

Hence, the results indicate that there is not merely disagreement among the three identified imaginaries, but also between these and the *'Circular construction by 2050'* imaginary. Regardless of the *de facto* existence and severity of the sector's CO_2 emissions, it seems unlikely that actors from the three identified imaginaries will be mobilized by this framing. Policymakers could, on the contrary, gain support from the three imaginaries by incorporating modular designs and design-for-disassembly as solution strategies. Policymakers could reframe problems/solutions accordingly to redirect patterns of innovation in response to the societal challenges.

6.6. Discussion

In what follows, Section 6.6.1 reflects on the implications of this paper. Section 6.6.2 proceeds by discussing how policymakers can navigate contested problem-solution spaces, and thus offers ways forward. Section 6.6.3 expands on some limitations and opportunities for future research, which is followed by concluding remarks in Section 6.6.4.

6.6.1. Operationalizing problem-solution spaces with Q-methodology

This paper demonstrated how the contestation in the problem-solution space can be operationalized through Q-methodology using various types of sources: by combining and comparing data of interviews, a survey, and policy documents. Accordingly, we illustrate how divergent imaginaries can be identified, described, and compared to understand the way and extent to which challenges are contested. Although Q-methodology has been used to understand contestation before (e.g., Cuppen, 2012; Gruszka, 2017; Ligtvoet et al., 2016; Rodhouse et al., 2021), our contribution lays in offering a systematic approach to deconstruct contestation in terms of problem-oriented and solution-oriented disagreement. By differentiating these two spaces, researchers and practitioners can scrutinize one of these two parts further. In our illustrative case for instance, the mean rankings (Table 6-5) indicate that the Dutch circular construction sector is more convergent in the solution space than in the problem space – particularly in imaginary 3. This suggests circular construction to be a "solution in search of a problem" (Wanzenböck et al., 2020, p. 478). Actors could subsequently examine in more depth why the problem space is contested (e.g. information asymmetries or incompatible value-systems) so that actors can further consolidate a shared understanding of circular construction's problem space. The operationalization of this paper thus helps advance research on problem-solution spaces, and helps actors analyze and navigate the contestation of any given societal challenge.

6.6.2. Policy implications: navigating contestation

The operationalization of the problem-solution space by means of Q-methodology has various implications for policy. Because policymakers increasingly deploy challenge-led policies to create shared understandings and mobilize stakeholders into a uniform direction (Hekkert et al., 2020; Mazzucato, 2018, 2017), learning from diverse and conflicting worldviews is required to avoid transformational failures (Schot and Steinmueller, 2018; Weber and Rohracher, 2012). Without a reflexive governance (Voß and Bornemann, 2011), policymakers may acquire the false impression that views on problems and solutions are widely shared (Wanzenböck et al., 2020). The operationalization of the problem-solution space is not merely a reflexive exercise for policymakers, but it also stimulates participants of the Q-study to reflect on problems and potential solutions that could be taken for granted.

Disagreement prompts the question of how contestation should be navigated. We argue that our reflexive exercise contributes to *constructive approaches* (Cuppen, 2012; Ligtvoet et al., 2016) by yielding insights that could enhance mutual understanding necessary to find common ground, establish compromises, or reframe problems and solutions. In our case, such an approach could lead to more support for modular designs and design-for-disassembly. While this is promising, mutual understanding is insufficient for overcoming disagreements that are rooted in fundamentally incompatible values and worldviews (Blok and Lemmens, 2015; Schon and Rein, 1994). Impasses are preferably avoided as not acting may be seen as the prioritization of one imaginary over the other. What is more, reflexivity on the normative divergence in the problem-solution space does not necessarily inform policymakers about the epistemological nature of problems and solutions (e.g., what solutions are *de facto* effective?). For example, stakeholders can disagree about the necessary 'radicality' of solution pathways. While some transformations require 'small wins' and/or short-term solutions, others would benefit from radical and/or long-term ones (Bours et al., 2021; Termeer and Dewulf, 2019).

A default approach for policymakers is to rely on evidence-based visions of scientific experts. Yet, this is problematic for the reason that researchers can likewise hold divergent views as we show in our illustrative case. In addition, the input of other actors should not be disregarded because they have a qualitatively different, but complementary, expertise through experience. Such *experts by experience* are confronted with the problem, and are crucial for the implementation of solutions (Wanzenböck and Frenken, 2020). When contestation is rooted in incompatible values and worldviews, and exacerbated by epistemic uncertainty, policymaking tends to be highly problematic.

To deal with this, scholars recently suggested that *agonistic approaches* may offer a way out. According to this approach, decisions are made while recognizing that fundamental disagreements are inevitable (Popa et al., 2021; Scott, 2021). In practice this means that policymakers need to make difficult decisions while acknowledging opposing imaginaries as rational (Mouffe, 2000). In our particular case, the three imaginaries could fundamentally disagree whether CO_2 emissions are problematic. An agonistic approach could then be to accept this worldview's incompatibility with the *'Circular construction by 2050'* imaginary, but to still demand a reduction of CO_2 emissions on epistemological grounds. The operationalization of the problem-solution space through Q-methodology is instrumental to revealing the source of disagreement, and thus helps understand whether a constructive or agonistic approach is more suitable.

6.6.3. Limitations and future research

We demonstrate an operationalization of the problem-solution space by means of Q-methodology. While Q-methodology is a broadly accepted research method that has existed already for nearly a century, it is important to stress a number of limitations (Brown, 1992; Stephenson, 1935). First, Q-methodology relies on statements that usually emerge from thematic analyses. While thematic analysis is a useful research method for identifying key aspects of large data sets, its methodological flexibility can lead to inconsistencies that affect the reproducibility of themes – in our case the problem and solution-oriented statements (Nowell et al., 2017). This is especially relevant for wicked problems research in which problem framings and solution framings interact in the sense that the framing of one may suggest the framing of the other. One should furthermore be aware of potential biases that emerged from the sampling strategies. Although we aimed to include actors across all actor types in our P-sample, no civil society organization was willing to partake in this study. Our results therefore hint that our mission-specific innovation system is distinct from many other systems in the sense that societal stakeholders have relatively little interest in its mission. Second, statistical studies of qualitative materials tend to treat quantitative results as 'real'. They are often objectified and reified. We would like to stress that our results and the underlying data (i.e., interviews, survey, and policy documents) are constructs. Our study may therefore come with epistemological limitations. For instance, notions like 'circular construction' may suffer from interpretative flexibility (Pinch and Bijker, 1984). Results should therefore be treated with caution.

Our study offers various avenues of future research. First, it examined contestation in a problem-solution space by identifying, describing, and comparing underlying conflicting imaginaries by using Q-methodology. Although this method is useful for identifying the variety of imaginaries, it does not yield an understanding of their ubiquity. A promising continuation of our operationalization would be to conduct large scale surveys that aim to understand the generalizability of imaginaries that were identified. Second, while Jasanoff & Kim (2009) argue that collectively held visions help understand socio-technical developments, our results suggest that various actors who hold power and agency have distinct visions that do not fit in dominant imaginaries. Considering the performative nature of these uncommon visions, future research could study such outliers when exploring futures. Third, both a strength and limitations of the problem-solution space is that it reduces the complex phenomenon of contestation to perspectives on problems and solutions. While this simplification provides an initial understanding of contestation, problem-solution spaces are situated in a wider socio-technical and path-dependent system in which worldviews are driven by underlying values. It would be valuable to examine these broader contexts, historical dimensions, and value systems from which imaginaries emerge. For example, a better appreciation of the values at play would help understand whether either constructive or agonistic approaches are more appropriate. Fourth, this study provides a snap shot of a contested problem-solution space. Yet, imaginaries change over time. Capturing their temporal nature would therefore provide insight into the dynamics of imaginaries and societal challenges. We speculate, for example, that imaginaries may either drift apart or move closer to each other – causing polarization or unification. Apart from gaining a deeper understanding, such an approach would provide useful insights for developing policy instruments aimed at problem-solution convergence. Fifth, our operationalization is applied to the circular construction sector. Future applications of other problem-solution spaces would provide more insight into the usefulness of the approach.

6.6.4. Concluding remarks

This study contributes to the literature on problem-solution spaces and reflexive governance by offering an operationalization that identifies, describes, and compares conflicting imaginaries of wicked problems and potential solutions by means of Q-methodology. To demonstrate this operationalization, we applied the approach to the case of the Dutch circular construction and identify divergent imaginaries that coexist with the government-constructed imaginary *'Circular construction by 2050'*. This study identified three imaginaries that help us understand contestation. We named these imaginaries (1) '*We need to use less resources more efficiently'*, (2) *'Let's reimagine design strategies'*, and (3) *'Construction needs a mix of solutions'*. We revealed various (dis)agreements between the imaginaries and diagnosed circular construction as a 'solution in search of a problem'. Operationalizing contested problem-solution spaces prompts the questions of how to navigate disagreement. This paper discusses how constructive and agonistic approaches may offer ways forward to shape a collective response. While this study explores and links the notions of imaginaries, contestation, and problem-solution spaces, we advocate future research that helps us further understand how to arrive at a shared understanding of both societal problems and their required solutions. This would help actors more effectively address the societal challenges of our time.

7. Responsible Innovation and Societal Challenges: The Multi-Scalarity Dilemma

7.1. Responsible Innovation and the Multi-Scalarity of Societal Challenges

The academic discourse on Responsible (Research and) Innovation - hereafter 'Responsible Innovation' - focuses on anticipatory, inclusive, reflexive, and responsive approaches to "stewardship of science and innovation in the present" (Stilgoe et al., 2013, p. 1570). The European Commission and various researchers believe that these approaches have the potential to address societal challenges (e.g., Genus and Stirling, 2018; Owen et al., 2020, 2012; Schomberg and Hankins, 2020; Von Schomberg, 2013). As such, Responsible Innovation resonates with a broader discourse, also known as the third frame (Schot and Steinmueller, 2018), that considers science and innovation important drivers for overcoming challenges like pandemics, climate change, and social injustice.

Societal challenges frequently fall in the category of wicked problems (Rittel and Webber, 1973) and are characterised by their multi-scalarity (Wanzenböck et al., 2020). We understand multi-scalarity as an attribute that is both fixed (i.e., place-based and geographical) and fluid (i.e., relational and constructed; c.f., Born & Purcell, 2006; Brown & Purcell, 2005; Gibson-Graham, 2002; Massey, 2004). It refers to the idea that wicked problems exist, unfold, and interact at multiple scales, and that 'grand' challenges are not contained but nearly always surpass geographical borders. An (in)action in one region may influence the conditions and capabilities of other regions (Jasanoff, 2013). Although uniform resolutions to these grand challenges may seem appealing, regions are affected by challenges in unique and unequal ways whilst the success of resolutions is context-dependent (Wanzenböck and Frenken, 2020). In addition, what is deemed responsible in one region, may not be considered so in another.

What is more, innovators design resolutions in unique local contexts while commonly assuming to create scalable resolutions that fit into global frames (Pfotenhauer et al., 2022). However, such local resolutions often neglect global implications whereas scalable resolutions frequently obscure local diversities.

Therefore, resolving societal challenges requires innovators to think both locally and globally when dealing with the complexity, uncertainty, and contestation associated with wicked problems (Farrell and Hooker, 2013; Wanzenböck et al., 2020).

In light of these challenges, this paper aims to draw attention to an important but largely overlooked question: How should Responsible Innovation deal with the multi-scalarity of societal challenges?

Some scholars argue that the scale at which Responsible Innovation operates principally depends on the scale of its anticipated impacts (Figure 7-1; Fitjar et al., 2019). Local (or global) impacts call for local (or global) anticipatory and reflexive deliberations. Although an innovation's impact is uncertain (Hoffmann-Riem and Wynne, 2002), innovators make *ex ante* assumptions and decisions that influence the scale at which they expect to make an impact. The reasoning behind these scales plays a crucial role in dealing with multi-scalarity but has been largely overlooked in the discourse of Responsible Innovation – especially in the context of grand challenges.

Two prevalent lines of reasoning involved in the 'politics of scaling' include the local reasoning and the global reasoning[17], each offering epistemic and normative advantages and disadvantages (Pfotenhauer et al., 2022). As we will discuss, local approaches are generally believed to be more grounded in local values and worldviews, while global approaches are associated with more collective and systemic responses. Let us first discuss arguments in favour of each approach, before exploring how multi-scalarity can be dealt with.

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17 We would like to stress that the notions 'local' and 'global' suffer from interpretative flexibility and that the ways these scale layers are understood may very accordingly (Gibson-Graham, 2002). We nevertheless use these terms for matters of simplicity to enhance the understandability of the multi-scalarity dilemma.

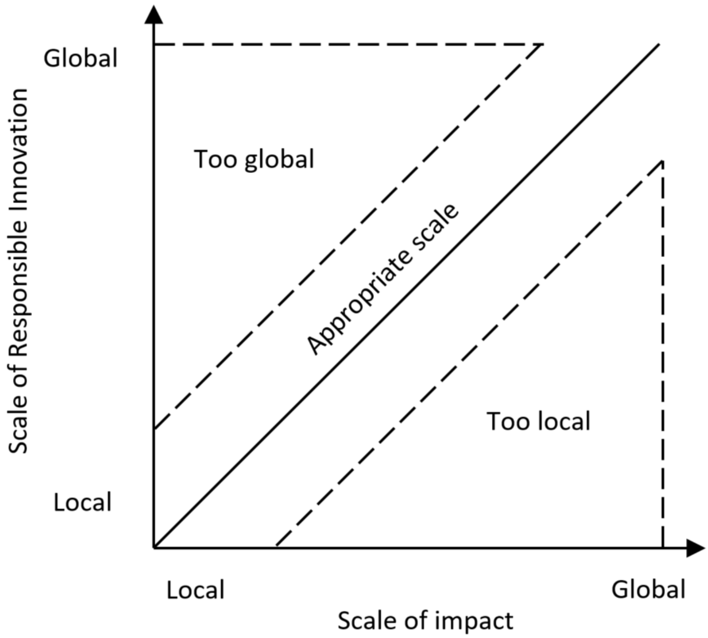

Figure 7-1: A multi-scalar approach to Responsible Innovation. Illustration adapted from Fitjar et al. (2019).

7.2. Arguments Favouring a Local Approach

Various scholars plead for Responsible Innovation to be grounded in local contexts by drawing on local values and worldviews (e.g., Hooli et al., 2019; Koirala et al., 2018). This is likewise encouraged by the European Commission by reason of the subsidiarity principle that prescribes to take decisions as close as possible to citizens (Wanzenböck and Frenken, 2020). Many European-funded projects on Responsible Innovation have taken a local, regional, or territorial turn, e.g., TeRRIFICA, TRANSFORM, TetRRIS, and CHERRIES. Studies similarly adopted concepts from regional innovation studies (Martikainen et al., 2021; Rehfeld, 2019; Thapa et al., 2019; Uyarra et al., 2019) such as regional innovation systems (Benneworth et al., 2019; Floysand et al., 2020), regional development (Barton et al., 2019), and Research and Innovation Strategies for Smart Specialization (RIS3; Fitjar et al., 2019).

Perhaps the most prevalent argument that support such an approach rests on the notion that societal challenges are contextual as they "affect places in different ways and to different extents" (Wanzenböck and Frenken, 2020, p. 56). Engaging with local stakeholders may help understand how they experience challenges in their unique way (Kerr et al., 2007) and thus benefits the 'problematization' phase of research and innovation (Franssen, 2022). Regions differ in how they make sense of problems and how they reason to resolve them (Jasanoff, 2013). For example, there are considerable differences in how regions conduct assessments of emerging technologies (Delvenne and Rosskamp, 2021).

In terms of resolutions, the distinctiveness of regions may obstruct their compatibility with standardized approaches. The implementation of resolutions takes place in unique contexts that are hard to grasp by conventional, often spatially distant, experts and policymakers (Macfarlane, 2003). *In situ* interactions stimulate learning as tacit knowledge is hard to obtain through 'global pipelines' that predominantly offer codified knowledge (Bathelt et al., 2004). Recognizing the heterogeneity of local publics helps understand the normative pluralism that would otherwise be homogenized (Pesch et al., 2020) and which is essential for constructive approaches to conflict resolutions (Cuppen, 2012; Ligtvoet et al., 2016). Engagement with locals furthermore contextualizes potential ramifications by making them more concrete (Pesch et al., 2020). Local stakeholders do not merely enrich innovation processes, they may even propose resolutions themselves (von Hippel, 1986). Bottom-up resolutions tend to enjoy considerable support (Smith et al., 2014).

In addition, reducing the scope of Responsible Innovation to a local scale tends to be more feasible than extending its scope to a global one (Fitjar et al., 2019; Lubberink et al., 2017b). Local considerations are more homogenous than global considerations, and identifying and navigating these global considerations requires immense resources that many innovators do not possess. While global approaches usually require lengthy negotiations that generally reinforce dominant views or lead to inadequate compromises (Ludwig et al., 2021), local approaches may respond more quickly to urgent challenges that require radical resolutions.

Ultimately, the uptake of local considerations enables innovators to resolve challenges according to context-specific values, worldviews, and conditions, which suggests that these local resolutions may be more aligned, effective, and socially desirable for local stakeholders.

7.3. Arguments Favouring a Global Approach

Let us now turn to some prevalent arguments in favour of a global approach. A central argument supporting a global scale is that most societal challenges are not spatially contained. First, one region's (in)action affects the condition of other regions (Jasanoff, 2013; Wanzenböck and Frenken, 2020). For example, how two adjacent regions individually respond to riverine (fluvial) flood risks can contribute directly to the flood safety of the neighbouring region. Second, problems may emerge in one region as symptoms of supra-regional phenomena. For instance, local (coastal) flood risks can result from global climate change-induced sea-level rise.

Responsible Innovation pleads for actors to become mutually responsive, and to bear a shared responsibility that is distributed among stakeholders (Owen et al., 2020; Van Oudheusden, 2014; Wiarda et al., 2021). It is precisely this geographically distributed nature of stakeholders that endorses global responses – stakeholders are not solely situated within one's region. While the 'Global North' is generally deemed a driver of innovation (Florida, 2010, 2005), it is the 'Global South' that tend to be most vulnerable to societal challenges (Ludwig et al., 2021). Some scholars therefore argue that the Global North has the moral obligation to include the Global South in its innovation processes (Schroeder and Kaplan, 2019). Taking responsibility for global challenges could avert a potential tragedy of the commons (Hardin, 1968), and may even prevent maladaptive forms of problem shifting from one region to another (Magnan et al., 2016).

Despite the place-dependent nature of know-how (Florida, 2010, 2005; Heimeriks and Balland, 2016; Hidalgo et al., 2007), local knowledge may not adequately match the challenge at hand. Regions benefit from global innovation systems because the knowledge, actors, and capital needed to realize resolutions are globally distributed and thus surpass regional boundaries (Binz and Truffer, 2017).

Furthermore, local approaches are frequently deemed to lack the capacity and scale needed to resolve grand challenges (Uyarra et al., 2019). They are inclined to address low-level symptoms that fail to adequately address high-level problems, causing a societal challenge to "no longer shows its teeth before it bites" (Churchman, 1967, p. 141). What is more, 'small wins' only become effective once they accumulate as nodes in a larger network (Bours et al., 2021; Termeer and Dewulf, 2019). Many scholars plead to meet 'big problems' with 'big science' (Ergas, 1987; Mazzucato, 2018a) because individual regions frequently lack the resources to resolve societal challenges comprehensively (Uyarra et al., 2019). The effectiveness of inter-regional responses partly stems from their economies of scale, spillover effects, and institutional complementarities that allow a response's sum to be greater than its parts.

On a more conceptual note, a globally coordinated approach allows for more cumulative patterns of innovation that increase the pace at which society can respond to societal challenges (Dosi, 1982; Mazzucato, 2017). The transformative change required to address societal challenges benefits from synergies and mutual learning among regions (Coenen et al., 2012; Coenen and Truffer, 2012). This is important for matters of directionality, but also for mitigating reflexivity failures (i.e., inadequate forms of reflection, anticipation, and inclusion in processes of self-governance), policy coordination failures (i.e., incoherency in policies across scales), and demand articulation failures (i.e., the insufficient understanding of future demands; Weber and Rohracher, 2012).

7.4. Navigating the Multi-Scalarity Dilemma: A Hybrid Approach

We observe that most studies exclusively focus on one of these two approaches while overlooking the importance of other scales (e.g., (trans-)national). If challenge-led forms of Responsible Innovation are to live up to their promise, they cannot ignore the multi-scalarity of the wicked problems they intend to resolve. Operating on all scales is necessary in our view, and we do therefore not unconditionally support an exclusive focus on a single scale. Indeed, multi-scalarity urges innovators to ground resolutions in local values and worldviews, but it also requires them to fit these into global efforts that drive systemic responses. As such, multi-scalarity imposes a dilemma on innovators who need to navigate the contradicting considerations between different scales (Figure 7-2). To deal with this dilemma, we advocate a hybrid approach that reaps benefits from multiple scales. In what follows, this section discusses three tentative scale-related considerations that could contribute to such an approach.

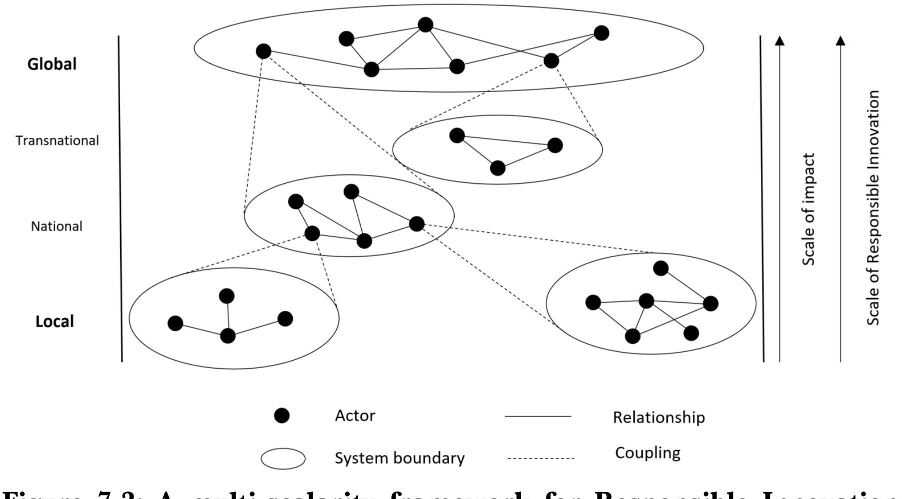

Figure 7-2: A multi-scalarity framework for Responsible Innovation. Inspired by Binz and Truffer (2017).

Combine complementary approaches. Managing the multi-scalarity of wicked problems requires innovators to understand that problem-resolutions framings may differ between scales of analysis (Wanzenböck et al., 2020). For instance, while climate change-induced sea-level rise generally represents a high-level problem framing on a global scale, individuals may frame this phenomenon differently at a lower-level scale by focusing on local flood hazards. Understanding the values and worldviews of stakeholders at different scales requires Responsible Innovation to apply different, but complementary, approaches that are suitable for each scale. Focus groups, co-design methods, and science cafes are exemplary approaches that operate at small scales, whereas standards, technology assessments, and innovation policies tend to be associated with larger scales (Doorn et al., 2013). By combining complementary approaches, Responsible Innovation could establish multi-level capacities that embed responsibility on multiple scales (Fisher and Rip, 2013).

Leverage boundary objects. To safeguard local diversities when driving cooperation, Responsible Innovation could benefit from boundary objects. These are constructs "that are plastic enough to adapt to local needs …, yet robust enough to maintain a common identity across sites." (Star and Griesemer, 1989, p. 393). They facilitate communication and collaboration across boundaries as they can be interpreted and used in different ways (Bechky, 2003). Exemplary boundary objects in the context of societal challenges include Sustainable Development Goals and societal missions (Mazzucato, 2018b; UN, 2022). These boundary objects help mobilize regions into a shared direction, while arguably providing space for their own integrity and ingenuity. To effectively address societal challenges, boundary objects need to be clear, targeted, measurable, and time-bound (Mazzucato, 2018a). In light of the contested nature of wicked problems and resolutions, boundary objects should be co-created in inclusive settings that help bridge contradicting values and worldviews (Janssen et al., 2023). This may for instance be done through so-called hybrid forums (Callon et al., 2009) or arenas (Loorbach, 2010; Wesseling and Meijerhof, 2021).

Embrace conflict. Wicked problems are inevitably associated with disagreement because of the heterogeneous values and worldviews across regions and scales. Decisions tend to result in 'winners' and 'losers'. Responsible Innovation should not assume consensus, but should learn from disagreement and diversity (Schot and Steinmueller, 2018). Constructive approaches yield insights that stimulate mutual learning needed to identify common ground, potential compromises, and fundamental disagreements (Cuppen, 2012; Ligtvoet et al., 2016). In case of fundamentally opposing views, innovations may be viewed as responsible by some stakeholders but deemed irresponsible by others. Various scholars suggest that Responsible Innovation could consequently build on agonistic approaches by acknowledging opponents as rational when making hard decisions (Popa et al., 2021; Scott, 2021). This prompts the question of who will make, and benefit from, these decisions (Stilgoe et al., 2013). As Responsible Innovation aims to be actionable, decisions will need to be made. In line with agonism, this calls for transparency – and by extension accountability – to communicate the bases of these difficult decisions (Fraaije and Flipse, 2020).

7.5. A Geographical and Relational Perspective on Responsible Innovation

In this paper, we explored the multi-scalarity dilemma that Responsible Innovation faces in the context of societal challenges. We discussed three tentative considerations that could contribute to a hybrid approach that safeguards local diversities in light of global efforts. We subsequently advocate more research on how this dilemma should be navigated. For instance, large scale approaches (e.g., standardisation) tend to be performed by a select group of powerful stakeholders who seldom represent all interests (Wiarda et al., 2022). Future research could explore how local interest could better feed into such approaches. In addition, while large scale boundary objects (e.g., missions) have discursive and political power, there is limited evidence that they *de facto* impact the activities of local economies (Bierman et al., 2022). Empirical insights could validate/reject whether such boundary objects encourage local responsible innovation. Even if stakeholders from vulnerable regions are able to partake in large scale approaches and the design of boundary objects, they commonly lack the resources, time, and political power to meaningfully provide input (Biermann & Möller, 2019). This inability greatly reduces the potential value that conflict offers for challenge-led forms of Responsible Innovation, and raises the question of what decision-making approaches (e.g., agonism) enable responsible outcomes in these contexts. All these questions draw attention to the notions of power, justice and fairness.

It is important to stress that the multi-scalarity dilemma is part of a larger knowledge gap. The Responsible Innovation literature promotes *mutual* responsiveness to make innovations ethically acceptable (Von Schomberg, 2011). Taking this mutuality seriously requires regions to look beyond their borders and consider each other's considerations. Although there are scholarly debates on the geography of innovations (e.g., Asheim and Gertler, 2009; Balland et al., 2015;

Boschma, 2005), transitions (e.g., Coenen et al., 2012; Coenen and Truffer, 2012), and societal challenges (e.g., Flanagan et al., 2021), we still lack a geography of Responsible Innovation. A geography of Responsible Innovation would yield broader insights into the distributive nature of responsibilities, i.e., the spatial nature of inclusive, anticipatory, reflexive and responsive practices. Our understanding of the multi-scaliarty dilemma would also benefit from a relational perspective on Responsible Innovation (Albertson et al., 2021; Chilvers & Pallett, 2018). For example, we need insights into how inter-scale relations are constructed and how they give rise to hierarchical structures (e.g., interdependencies; Albertson et al., 2021). While regions may share responsibilities, they do not necessarily have an equal responsibility and agency (O'Neill, 1996; Young, 2006).

A geographical and relational perspective on Responsible Innovation could even challenge the current predominantly Western conceptualization of Responsible Innovation if other regions (e.g., the Global South) have different understandings of responsibility (Macnaghten et al., 2014; Wong, 2016). Because the notion of responsibility is culturally bound, we may never arrive at a shared understanding of responsibility (Lukes, 2011).

Studying the scale of Responsible Innovation could furthermore provide an awareness of which regions are included and excluded in innovation. It informs us about how innovators navigate considerations of different locations, and thus reveals which regions tend to benefit from innovation. Such research would draw explicit attention to power distributions and geopolitics as challenge-led innovations have substantial political and socio-economic implications. Consequently, we should revisit van Oudheusden's (2014) question in the spatial sense: "*Where* are the politics in Responsible Innovation?" (p. 67, emphasis added).

8. Conclusion

The main objective of the studies presented in this dissertation is to identify and explore various strengths and limitations of Responsible Innovation in addressing wicked societal challenges. In this final chapter, I will answer the research questions that I introduced in Chapter 1. I will then proceed by presenting the main conclusions of my work, and by reflecting on their broader implications for theory and practice. This includes avenues for future research.

8.1. Sub-Research Questions

The main research question of this dissertation follows: to what extent can the procedural approach of Responsible Innovation, understood as the AIRR framework, be used to resolve wicked societal challenges? In Chapter 1, I set out a series of sub-questions that help answer this main research question. The succeeding paragraphs will first answer these.

Chapter 2 aimed to answer Q1: what are the shared research topics, knowledge bases, and shared organisation of Responsible Innovation and Responsible Research and Innovation as a common ground for joint research? We used three scientometric analyses to identify the shared research topics, knowledge base, and organisation. These analyses concern a co-word analysis, a reference publication year spectroscopy, and a co-author analysis, respectively.

My results suggest that Responsible Research and Innovation was generally considered a policy-driven discourse introduced by the European Commission and funded through its H2020 projects. It leans towards von Schomberg's (2013) definition and focused on the six keys (i.e., public engagement, open access, gender equality, ethics, science education, and governance). Responsible Innovation, however, largely emerged from academic traditions like Science & Technology Studies and Ethics of Technology. In Responsible Innovation, the definition and theoretical framework of Stilgoe et al. (2013) are the most prominent. Their so-called AIRR framework pleads for procedural forms of anticipation, inclusion, reflexivity, and responsiveness to promote a forward-looking form of responsibility. Although the dimensions of Responsible Research and Innovation are fixed by the values anchored in the European Union, the dimensions of Responsible Innovation are intended to identify the values that should guide innovation in the first place. In the years following 2010, both notions gradually became interconnected in terms of topics and witnessed a proliferation of studies on responsibility in the context of (emerging) innovations. The shared academic organization of both notions appears fragmented as scholars predominantly work in small and isolated groups. This may impede the exchange of especially tacit knowledge. In light of the shared topics and knowledge base, however, there seems to be room for more collaboration among scholars. The results suggest that the concepts of Responsible Innovation and Responsible Research and Innovation have matured into an increasingly cumulative and interconnected research trajectory. We argue that their commonalities may have caused some conflation of the two concepts.

In Chapter 3, I proceeded by answering Q2: what are the potential methodological strengths and weaknesses of Responsible Innovation approaches in coping with the wickedness characteristics of societal challenges? We systematically identified approaches from the Responsible Innovation literature that articulate anticipatory, inclusive, reflexive and responsive practices. I then followed Vermaas & Pesch (2020) by evaluating these approaches *a priori* against ten methodological conditions based on the underlying dimensions of wicked problems. The analysis is thus an analytical reconstruction that offers an initial understanding of these approaches. Therefore, it is important to stress that empirical manifestations may unfold differently than our conceptual inquiry. Our contribution should be interpreted with caution.

The results suggest that several Responsible Innovation approaches appear useful in the context of wicked problems. The strengths of Responsible Innovation seem to lay in treating problems as unique; including matters of concern next to matters of facts; seeking satisfactory results instead of optimal ones; determining aspects of societal goodness and social equity in view of normative plurality; and encouraging practitioners to be aware of cascading effects that take place and cause path-dependencies.

However, our analysis also hints at some methodological drawbacks of Responsible Innovation. Various approaches struggle to coevolve problem-resolution framings; they occasionally lack foresight and/or the explicit awareness of its limitations; they often overlook the notion that wicked problems are symptoms of other (interrelated) problems; and they frequently struggle to determine aspects such as responsibility and accountability in relation to their own practices as a result of their collective and deliberative nature. Overcoming these methodological drawbacks requires us to improve, combine, or reimagine approaches that have a greater shot at addressing challenges responsibly. This appears particularly urgent for the organizational context which currently lacks a rich pool of capable approaches.

In Chapters 4, 5, and 6, I empirically explored the strengths and limitations of some of the identified approaches of Responsible Innovation. Chapter 4 addressed Q3 by answering what factors motivate, obstruct, and facilitate the AIRR dimensions of Responsible Innovation in *de jure* standardisation. We identified 96 factors through in-depth interviews and a survey with practitioners. These revealed various instrumental, substantive and normative motives for responsible standardisation. Employees are not merely intrinsically motivated to meet their societal obligation, they also believe that responsible practices contribute to the credibility of standard developing organisations, enhance the quality of standards, and promote their market acceptance. Obstructing factors include amongst others the cost of stakeholders' participation and their unawareness of the standard-setting process. Prevalent facilitators for AIRR dimensions include the practitioners' training and the type of standard that they create. Furthermore, our results suggest that many practitioners deem the AIRR dimensions important for establishing socially desirable standards. Yet, a large number of them also believe that *de jure* standardisation is insufficiently able to develop socially desirable standards as they perceive the process as inadequately inclusive and anticipatory.

I continued in Chapter 5 by focusing on mission-oriented innovation policy as an approach to mobilize stakeholders behind shared goals, aimed at addressing societal challenges. We examined the effect of mission-orientations on the public participatory performance of innovation projects (Q4). We used project-level data to compute the statistical effect of (non-)mission orientations on the timing, openness, and (financial) influence of public participation in 1261 projects. We find that the specific mission theme is important for the participatory performance. Various themes predict upstream and midstream participation in contrast to downstream participation. Almost all mission themes correlate significantly with earlier participation and the number of public participants in most mission themes is likewise greater than in conventional projects. Yet, the majority of them did not explain the diversity of public participation. Compared to non-mission oriented projects, only half of the mission themes predict the financial influence of participation. As such, my results suggest that mission-oriented projects indeed correspond with earlier participation of more public actors, but we find little evidence that they also consistently coincide with increased diversity and financial influence of public participants.

The last Responsible Innovation approach that we studied was Q-methodology. In Chapter 6, we consequently addressed how Q-methodology informs us about divergent sociotechnical imaginaries on wicked problems and required solutions (Q5). We used the Dutch circular construction sector as my case study, and drew data from semi-structured interviews, policy documents, and a survey. We identified, described, and compared three different imaginaries in terms of their problem-oriented and solution-oriented visions. These insights informed me about disagreements and common ground, and could help policymakers co-evolve problem-solution framings. Our analysis suggests that policymakers linked to the Dutch circular construction sector could reap more support if they endorse modular designs and design-for-disassembly as solution pathways. We furthermore identified that stakeholders, in contrast to policymakers, perceive the sector's CO_2 emissions as relatively unproblematic. However, this approach did not provide insights into why this opposition emerged and whether this disagreement can be resolved. Q-methodology also did not inform us about the ubiquity of the identified imaginaries. We, therefore, find that such an approach has limitations that need to be compensated for.

In Chapter 7, we address a more holistic and conceptual question related to Responsible Innovation approaches in general. We claim that if challenge-led forms of Responsible Innovation are to live up to their promise, they cannot ignore the multi-scalarity of wicked problems they intend to address. Multi-scalarity refers to the idea that wicked problems exist, unfold, and interact at multiple scales. It prompts the question of how Responsible Innovation should deal with the multi-scalarity of societal challenges (Q6). We explain that some scholars suggest that the scale of Responsible Innovation principally depends on the scale of its anticipated impacts (Fitjar et al., 2019); local (or global) implications call for local (or global) reflexive and anticipatory deliberations. Yet, we argue that innovators make *ex ante* assumptions and decisions that influence the scale at which they expect to make an impact. We discuss that many scholars exclusively focus on one particular scale, commonly either through a local approach or global approach, without justifying this choice. We explore rationales for both these two prevalent but largely opposing options, and suggest that local approaches are usually more grounded in local values and worldviews, whereas global approaches enjoy more collective and systemic responses. Indeed, addressing societal challenges requires innovators to ground resolutions in local values and worldviews, while also fitting these into global efforts. Because we see a necessity in both scales, we advocate a hybrid approach and provide tentative insights into how

Responsible Innovation could cope with multi-scalarity: innovators could combine complementary approaches, leverage boundary objects, and embrace conflict.

8.2. Main Research Question

Now that I have answered the six sub-questions, let us turn to the main research question: to what extent can the procedural approach of Responsible Innovation, understood as the AIRR framework, be used to resolve wicked societal challenges?

Chapter 3 suggests that Responsible Innovation is good at treating problems as unique and in drawing attention to possible cascading effects of resolutions. It can extend anticipatory and reflexive deliberations from matters of fact to matters of concern, and include aspects of societal goodness and social equity in light of societal pluralism. However, the chapter also hints at various methodological limits of Responsible Innovation. Although approaches explore probable, possible, and desirable futures, approach-related articles rarely discuss the limitations of foresight. Approaches furthermore tend to struggle to coevolve problem-resolution framings as they frequently take (emerging) innovations as entry points for deliberations. Even when Responsible Innovation starts from the problem-space, it often overlooks the notion that wicked problems tend to be symptoms of other (interrelated) problems. Chapter 7 indicates that it is unclear how Responsible Innovation should deal with the multi-scalarity of wicked problems. Although a broad range of studies and approaches focus on the micro and macro scale, the meso scale (the organisational context) is frequently overlooked according to Chapters 2 and 3. This is important because institutionalising responsibility and addressing societal challenges require synergies between multiple scales (Fisher and Rip, 2013).

Chapter 4 and 5 indicate that including stakeholders – both in terms of their number and diversity – remains highly challenging even though inclusion forms a core dimension of Responsible Innovation. Chapter 6 shows that even if a diverse set of stakeholders is included, Responsible Innovation still needs substantial time and effort to navigate the complex and divergent epistemic and normative ideas regarding the problem-solution space. This is problematic because wicked problems generally require urgent resolutions, which Responsible Innovation struggles to offer. Some approaches (e.g., standardization) strive for consensus, but this is generally unattainable in the context of wicked problems (Chapter 4). It nevertheless remains unclear how Responsible Innovation should deal with opposing views. Responsible

Innovation generally focusses on including values and worldviews, but does not adequately inform us how these should be navigated.

8.3. Theoretical and Practical Implications

This dissertation has a broad range of implications for scholars and practitioners of Responsible Innovation, and of other adjacent fields such as (responsible) standardisation, mission-oriented innovation policy, and sociotechnical imaginaries. This section highlights the overarching implications that are particularly important for the relationship between Responsible Innovation and wicked societal challenges. Some of these implications have not been explicitly discussed in the chapters above.

8.3.1. Responsible Innovation as a dynamic boundary object

This dissertation shows how the notion of Responsible Innovation can yield support and collaboration across communities. Not only does the dimension of inclusion foster cooperation, the ambition to innovate responsibly and to address societal challenges can bring stakeholders together (Rip, 2016; Winter and Butler, 2011). This idea is supported by the results in Chapter 4 and 5. If we extend this finding, then we may conclude that Responsible Innovation functions as a boundary object. Boundary objects are (in)tangible artefacts that are plastic enough to be interpreted differently, but specific enough to create a common identity across communities. They create "shared vocabulary although the understanding of the parties would differ regarding the precise meaning of the term in question" (Brand and Jax, 2007, p. 9). For instance, Chapters 2 and Chapter 6 demonstrate how scholars and practitioners pursue responsible and challenge-led innovation despite their different understandings of these notions. Indeed, "Responsible Innovation: who could be against *that*?" (Guston, 2015, p. 1).

However, my work also suggests that responsible and challenge-led innovations are different from common technical and epistemic boundary objects (c.f., Ewenstein and Whyte, 2009) in the sense that their normative nature has the tendency to reveal contestation. The theoretical implication of this is that such 'normative boundary objects' tend to be effective in fostering collaboration when addressing tame problems but can lose this ability in the context of wicked problems. Consequently, collaboration may be difficult or even impossible when disagreement is rooted in fundamentally opposing values and worldviews. I therefore suggest that normative boundary objects may have a dynamic effect that is influenced by the wickedness of a given context.

8.3.2. Dealing with contestation

The phenomenon of contestation returned in many of my studies. While the meaning of Responsible Innovation can be one source of disagreement, we also discuss how contestation about problems and resolutions emerges between actors (Chapter 3), sectors (Chapter 2 & 4), imaginaries (Chapter 6), regions (Chapter 7), and scales (Chapter 7). In none of these cases there was an evident way forward. While numerous studies in Responsible Innovation focus on identifying heterogeneous values and worldviews of stakeholders, very few contributions help us understand how we should navigate this contested landscape. It is unclear whether Responsible Innovation can even be considered 'responsible' if, despite anticipatory and reflexive deliberations, decision-making does not reflect the heterogeneity of the stakeholders' values and worldviews. Responsible Innovation's inability to respond to conflict has important implications for its effectiveness in addressing societal challenges. This suggests that theory should be more careful in expressing optimism about challenge-led forms of Responsible Innovation. Hence, research may need to revisit the notion of responsiveness to better understand how practitioners should respond to conflict.

8.3.3. A multi-scalar approach to Responsible Innovation

Scholars plead for system-wide capabilities for Responsible Innovation (Fisher and Rip, 2013). Anticipatory, inclusive, and reflexive practices are deemed especially important when driving transformative change to address wicked problems (Wanzenböck et al., 2020; Weber and Rohracher, 2012). Chapter 2 finds that despite this recognition, very few articles about Responsible Innovation offer insights that could realize this ambition. Chapter 3 argues that studies and approaches of Responsible Innovation tend to focus on a particular scale of systems (i.e., micro, meso or macro scale). In Chapter 8, I argue that we need a multi-scalar approach to Responsible Innovation. For theory this means that Responsible Innovation should become more reflexive on how local diversities fit into global efforts, and how local considerations may be in conflict with global ones. Pursuing such a hybrid approach could mean that practitioners need to combine complementary approaches, leverage boundary objects, and view conflict as an opportunity for learning. I furthermore urge practitioners to look beyond their own context of application and consider the values and worldviews of other implicated regions – for instance those that are found upstream in the value chain. By doing so, practitioners could create more responsible innovation systems.

8.4. Limitations

My studies come with various limitations. Although a variety of them are discussed in the chapters of this dissertation, I would like to highlight some of the most important ones. First, I have focused on wicked problems as an entry point for understanding how Responsible Innovation relates to societal challenges. While this allowed us to study Responsible Innovation under some of the hardest conditions, there are many other typologies of societal challenges. Alternative types include so-called super wicked problems (Lazarus, 2009; Levin et al., 2012), complex problems (Head and Alford, 2015; May et al., 2013), and unstructured problems (Hoppe, 2011; Hurlbert and Gupta, 2015). What is more, the very characteristics of these typologies are subject to debate. In this dissertation, the ten wickedness characteristics as introduced by Rittel and Webber (1973) were used because they have arguably received most recognition within academia. Yet, scholars have recently also introduced a wide range of other characteristics that may require attention (Head and Alford, 2015; Ooms and Piepenbrink, 2021). Further, societal problems may not always fit perfectly into these typologies, but rather exhibit a selection or degree of these characteristics. Although some problems are fully tame or wicked, presumably, most lay somewhere in between (Alford and Head, 2017).

Second, some of the results in Chapter 3 lean on an analytical reconstruction that is aimed at offering an initial understanding of approaches. I cannot stress enough the limitation that has also been pointed out by Vermaas and Pesch (2020), that is, the empirical manifestations of approaches can unfold differently from the considerations in my *a priori* assessment. The respective insights are therefore tentative and require *a posteriori* validation.

Third, in Chapters 4, 5 and 6 we focused on specific approaches to better understand how they help innovators cope with wickedness. However, the empirical environment of Chapter 4 was not exclusively one of a wicked problem. In this specific chapter we examined how responsibility is institutionalized in standardisation in a broader sense, which yielded insights of which some could arguably be extended to the context of wicked problems, but some may not.

8.5. Future Research

This dissertation advances research on how to innovate responsibly for societal challenges. I recognise that this is a broad research area that offers numerous avenues for future research, many of which have been suggested in the preceding chapters of this dissertation. However, there are a number of areas for future research that I would like to highlight, and which I personally deem important in light of recent debates. These opportunities rest on three fundamental and broadly acknowledged premises:

1. Responsible Innovation necessitates anticipatory, inclusive, reflexive, and responsive approaches to shape innovations in accordance with values and worldviews of society (Stilgoe et al., 2013).
2. Resolving societal challenges requires anticipatory approaches to deal with uncertainty, inclusive approaches to cope with complexity, and reflexive approaches to navigate contestation (Head, 2008; Wanzenböck et al., 2020).
3. Resolving societal challenges will often demand transformative change of sociotechnical systems (Geels and Schot, 2007; Weber and Rohracher, 2012).

These premises suggest that inclusive, anticipatory, reflexive, and responsive approaches to societal challenges do not only help foster the ethical acceptability of individual innovations, but that they are also necessary for safeguarding the acceptability of broader socio-technical transformations that result from an accumulation of innovations. They urge us to cease fixating on solely *driving* transformations in terms of their acceptance and speed, and to extend this debate to desirably *shaping* transformations in terms of their acceptability and directionality. I therefore believe that future research should broaden the scholarly debate of Responsible Innovation to responsible sociotechnical change. This would lead to a better understanding of responsibility in dynamic, multi-scalar, multi-dimensional, and multi-actor innovation systems, which is important because many heated debates surrounding societal challenges do not revolve around a single innovation but instead relate to problems and transformations at large (e.g., the Dutch nitrogen crisis or energy transition).

I realise that a number of research streams reflect these premises and intentions. In particular, I see potential in the (re-)emerging discourse on mission-oriented innovation as a specific type of challenge-led innovation associated with transformative change. A strength of this discourse is that we are witnessing a rapid uptake of mission-oriented innovation by policymakers and funding agencies through various policies and funding schemes. Its uptake presents at least two windows of opportunity: to study these approaches in an empirical setting (1) and to truly make an impact (2). Chapters 5 and 6 already took mission-oriented innovation as their empirical contexts because this approach shares similarities with Responsible Innovation and is directed at wicked societal challenges. Mission-oriented innovation resonates with Responsible Innovation in the sense that both notions cherish anticipatory, inclusive, reflexive, and responses approaches.

There is a limited understanding of the *de facto* nature and role of mission-oriented innovation (Janssen et al., 2021a). Future research could seek inspiration from previous Responsible Innovation studies by raising similar questions. For instance, how are probable, possible, and desirable impacts of missions defined, foreseen, and evaluated?; who is included and excluded in mission-oriented innovation?; how should conflicting ideas surrounding these missions be navigated and reflected upon?; and do missions indeed effectively coordinate responses to societal challenges? These questions are not merely important for matters of responsibility, but they also play a crucial role in preventing demand articulation failures, directionality failures, reflexivity failures, and policy coordination failures, respectively (Weber and Rohracher, 2012).

Future research could examine mission-oriented approaches and instruments, e.g., government-funded projects, governance strategies, public procurement, and so-called mission arenas. We may also need novel approaches. For example, a mission-oriented technology assessment could help us explore the risks and benefits that sociotechnical change poses to missions and our society. Nevertheless, scholars should not reinvent the wheel. They can draw valuable lessons from Responsible Innovation to shape transformations in accordance with societal values and worldviews. The goal should be to resolve challenges, not to create new ones. The stakes are incredibly high.

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Appendix

Appendix A - Chapter 2

A.1. RRI/RI keyword frequency analysis

This appendix shows the most common keywords in the literature of Responsible (Research and) Innovation.

Title word	**N.**	**Abstract words**	**N.**	**Author keywords**	**N.**
INNOVATION	287	INNOVATION	1048	RESPONSIBLE RESEARCH AND INNOVATION	143
RESPONSIBLE	241	RESPONSIBLE	619	RESPONSIBLE INNOVATION	119
SCIENCE	36	RRI	591	ETHICS	37
RRI	34	TECHNOLOGY	285	GOVERNANCE	32
RESPONSIBILITY	33	SCIENCE	281	INNOVATION	27
CASE	31	SOCIAL	281	NANOTECHNOLOGY	25
GOVERNANCE	31	PAPER	272	RESPONSIBLE RESEARCH AND INNOVATION (RRI)	22
TECHNOLOGY	30	ETHICAL	230	EMERGING TECHNOLOGIES	21
DEVELOPMENT	25	DEVELOPMENT	224	PUBLIC ENGAGEMENT	21
ETHICS	25	TECHNOLOGIES	204	TECHNOLOGY ASSESSMENT	21
ASSESSMENT	20	GOVERNANCE	190	RESPONSIBILITY	20
PUBLIC	20	POLICY	186	RRI	17
SOCIAL	19	SOCIETAL	178	SYNTHETIC BIOLOGY	17
TECHNOLOGIES	19	PUBLIC	173	SUSTAINABILITY	14
EMERGING	17	APPROACH	164	STAKEHOLDER ENGAGEMENT	12
ENGAGEMENT	17	STUDY	153	ANTICIPATION	8
ETHICAL	17	FRAMEWORK	152	CORPORATE SOCIAL RESPONSIBILITY	8
POLICY	17	RESPONSIBILITY	148	PARTICIPATION AND SCIENCE GOVERNANCE	8
SOCIETY	17	SOCIETY	146	SOCIOTECHNICAL INTEGRATION	8
SYNTHETIC	17	PROCESS	145	BIG DATA	7
BIOLOGY	16	EMERGING	140	FORESIGHT	7
PROJECT	16	STAKEHOLDERS	139	ICT	7
EDUCATION	15	CHALLENGES	132	SCIENCE POLICY	7
EUROPEAN	15	ARTICLE	130	SOCIAL INNOVATION	7
PERSPECTIVE	15	DATA	128	SUSTAINABLE DEVELOPMENT	7
STUDY	15	WILL	128	ANTICIPATORY GOVERNANCE	6
APPROACH	14	EUROPEAN	125	INDUSTRY	6
HEALTH	14	ISSUES	125	ARTIFICIAL INTELLIGENCE	5
HUMAN	14	ENGAGEMENT	119	CORPORATE SOCIAL RESPONSIBILITY (CSR)	5
MANAGEMENT	14	FUTURE	117	ENGAGEMENT	5

A.2. RI keyword frequency analysis

This appendix shows the most common keywords in the literature of Responsible Innovation.

Title words	**N.**	**Abstract words**	**N.**	**Author keywords**	**N.**
INNOVATION	180	INNOVATION	671	RESPONSIBLE INNOVATION	113
RESPONSIBLE	142	RESPONSIBILITY	383	INNOVATION	31
CASE	20	SOCIAL	188	RESPONSIBLE RESEARCH AND INNOVATION	31
DEVELOPMENT	18	TECHNOLOGY	163	ETHICS	19
TECHNOLGY	18	PAPER	134	GOVERNANCE	18
GOVERNANCE	16	ETHICAL	122	NANOTECHNOLOGY	14
RESPONSIBILITY	15	DEVELOPMENT	121	RESPONSIBLITY	12
PUBLIC	14	TECHNOLOGIES	118	SUSTAINAIBLITY	10
ETHICS	13	GOVERNANCE	114	TECHNOLOGY ASSESSMENT	10
SOCIAL	13	RRI	114	PUBLIC ENGAGEMENT	9
SOCIETY	13	RI	106	TECHNOLOGY	9
STUDY	13	PUBLIC	104	EMERGING TECHNOLOGIES	8
MANAGEMENT	12	SCIENCE	101	STAKEHOLDERS ENGAGEMENT	8
SCIENCE	12	STUDY	100	RESEARCH	7
TECHNOLOGIES	11	SOCIETAL	98	SOCIO-TECHNICAL INTEGRATION	7
ASSESSMENT	10	FRAMEWORK	87	SOCIAL INNOVATION	6
CHALLENGES	10	POLICY	87	SYNTHETIC BIOLOGY	6
FRAMEWORK	10	APPROACH	82	AGRICULTURE	5
APPROACH	9	SOCIETY	73	ANTICIPATORY GOVERNANCE	5
DESIGN	9	CHALLENGES	72	INDUSTRY AND INNOVATION	5
ETHICAL	9	EMERGING	70	NEUROIMAGING	5
HEALTH	9	ETHICS	69	RESPONSIBLE	5
PERSPECTIVE	9	ARTICLE	68	RRI IN INDUSTRY	5
BIOLOGY	8	PRACTICES	68	RRI KPI'S	5
CARE	8	RESPONSIBLE	68	RRI METRICS	5
HUMAN	8	WILL	67	TECHNOLOGIES	5
INDUSTRY	8	DATA	65	ANTICIPATION	4
PRACTICE	8	POTENTIAL	65	BIG DATA	4
TECHNOLOGICAL	8	VALUES	65	DESIGN	4
AGRICULTURE	7	INDUSTRY	64	ENGAGEMENT	4

A.3. RRI keyword frequency analysis

This appendix shows the most common keywords in the literature of Responsible Research and Innovation.

Title words	**N.**	**Abstract words**	**N.**	**Author keywords**	**N.**
INNOVATION	136	RRI	586	RESPONSIBLE RESEARCH AND INNOVATION	92
RESPONSIBLE	120	INNOVAITON	469	INNOVATION	23
RRI	34	RESPONSIBLE	282	ETHICS	21
SCIENCE	22	SCIENCE	152	RESPONSIBLE INNOVATION	18
RESPONSIBLITY	21	PAPER	131	RESPONSIBLITY	14
CASE	14	TECHNOLOGY	118	RRI	14
GOVERANNCE	11	SOCIAL	107	GOVERNANCE	13
TECHNOLOGY	11	SOCIETAL	102	RESPONSIBLE RESEARCH AND	12
ASSESSMENT	10	ETHICAL	101	RESPONSIBLE RESEARCH AND INNOVATION (RRI)	12
EDUCATION	9	DEVELOPMENT	99	NANOTECHNOLOGY	8
EMERGING	9	POLICY	91	STAKEHOLDER ENGAGEMENT	8
ETHICS	9	APPROACH	89	TECHNOLOGY ASSESSMENT	8
PRACTICE	9	RESPONSIBILITY	81	ENGAGEMENT	7
DEVELOPMENT	8	PROCESS	80	PARTICIPATION AND SCIENCE GOVERANCE	7
ENGAGMENT	8	FRAMEWORK	79	RESPONISBLE	7
EUROPEAN	8	TECHNOLOGIES	79	TECHNOLOGY	7
POLICY	8	EUROPEAN	78	EMERGING TECHNOLOGIES	6
TECHNOLOGIES	8	GOVERNANCE	71	SYNTHETIC BIOLOGY	6
FUTURE	7	SOCIETY	68	ASSESSMENT	5
LEARNING	7	STAKEHOLDERS	67	ICT	5
PROJECT	7	CHALLENGES	66	INDUSTRY	5
ICT	6	EMERGING	65	INDUSTRY AND INNOVAITON	5
INDUSTRY	6	PROJECT	64	PUBLIC ENGAGMENT	5
PERSPECTIVE	6	PROCESSES	63	RESEARCH	5
SCHOOL	6	ISSUES	62	RRI IN INDUSTRY	5
SOCIAL	6	CONCEPT	61	RRI KPIS	5
SYNTHETIC	6	PUBLIC	58	RRI METRICS	5
APPROACH	5	ARTICLE	57	INNOVATION (RRI)	4
BIOLOGY	5	RESEARCHER	56	IRRESISTIBLE PROJECT	4
BRAIN	5	WILL	56	RESEARCH AND INNOVATION	4

Appendix B - Chapter 3

B.1. Crude descriptions of Responsible Innovation approaches

This appendix provides very short descriptions of the identified Responsible Innovation approaches.

Approach	Short description	Example of reference
Anticipatory governance	The anticipatory management of emerging innovations in the upstream phases of development	(Muiderman et al., 2020)
Innovation policy	Institutional instruments to govern patterns of research and innovation	(Fitjar et al., 2019)
Institutions	Implicit/explicit rules and norms	(Wickson and Forsberg, 2015)
(Macro) monitoring	The use of indicators to observe macroscale phenomena	(Mejlgaard et al., 2018)
Open Access	A system in which content is available to everyone	(Ruggieri et al., 2021)
Public accountability	The condition of being held accountable by societal actors	(Leese, 2017)
Public procurement	The process in which authorities purchase innovations	(Uyarra et al., 2019)
Research funding	The allocation of resources for knowledge production	(Gildenhuys, 2020)
Responsible port innovation	Dealing with value (conflicts) in port development	(Ravesteijn et al., 2015)
Strategic niche management	The management of protected spaces for, often experimental, innovations	(Metze et al., 2017)
Technology assessment	An interactive process to proactively understand the societal impact, and embedding of, innovations	(Rip and van Lente, 2013)
Action plans	A combinations of procedures (e.g., context analyses) to attain RRI-related change	(Colizzi et al., 2019)
Cycles of actualization	A reflective mechanism to continuously experiment with better practices	(Batayeh et al., 2018)
Education methods	Teaching approaches to enable student learning	(Wickson et al., 2015)
Ethics and advisory committees	A panel that provides directions based on its (ethical) reflections	(Armstrong et al., 2012)
Maturity model	A tool that facilitates the integration of RRI in organizations	(Stahl et al., 2017)
(Meso) monitoring	The use of indicators to observe mesoscale phenomena	(Yaghmaei, 2018)
Open innovation	The practice of acquiring input for innovations from external sources	(Long and Blok, 2018)
RMoI tool	A systematic tool to identify and consider socio-ethical risks and opportunities	(Long et al., 2020)
Social labs/Living labs	Interactive and protective spaces for social experimentation	(Timmermans et al., 2020)
Co-design	A range of collaborative and creative methods for innovation	(Macken-Walsh, 2019)
Communication methods	Approaches for the exchange of information	(Gertrudix et al., 2021)

Approach	Short description	Example of reference
Consultation methods	Approaches to acquire advice from external actors	(Capurro et al., 2015)
Delphi methods	A collaborative approach for reaching consensus	(Brier et al., 2020)
Embedded ethicist/social scientist	The integration of socio-ethical experts in innovation to enhance reflexive capacities	(Schuurbiers, 2011)
Engagement	Interactions with external actors (e.g., communication, consultation, and participation)	(Bauer et al., 2021)
Ethical matrix	A decision-making framework to understand ethical aspects from multiple stakeholders' perspectives	(Bremer et al., 2015)
Focus groups	A collective exercise to discuss topics of interest	(Lynch et al., 2017)
Foresight methods	The practice of foreseeing possible futures	(Barre, 2014)
Horizon scanning	The early detection and assessment of emerging innovations and their accompanied risks	(Fleming et al., 2021)
Imaginaries	Collectively held normative and socio-technical visions for the future	(Roßmann, 2021)
Life cycle assessment	The analysis of an innovation's environmental impact – from design to disposal	(Wender et al., 2014)
Narratives	The act of sharing a storyline	(van der Meij et al., 2017)
Participation methods	The involvement of external actors in two-way communication and sometimes decision-making	(Mouter et al., 2021)
Procedural safeguards	Protective mechanisms incorporated in processes of research and innovation (e.g., informed consent)	(Boers et al., 2018)
Q-method	A procedure to identify and understand the variety of perspectives on a particular topic	(Schuijff et al., 2021)
Risk assessment	The identification and appraisal of risks	(Miller, 2015)
Scenarios	The construction of possible socio-technical futures to explore their plausibility and desirability	(Betten et al., 2018)
Science shops/Science cafes	Spaces for science-society interactions	(Urias et al., 2020)
Slow innovation	A slow approach to innovation to create time for inclusion, anticipation, reflexivity, and responsiveness	(Steen, 2021)
Value sensitive design	Identifying and considering values (conflicts) in innovation	(Dignum et al., 2016)
X-by-design/design-for-X	Aligning innovations with a particular value (e.g., safety, health, privacy)	(van Gelder et al., 2021)

Appendix C - Chapter 4

C.1. Interview questions

This appendix presents the interview questions that were used for the semi-structured interviews. The questions are translated from its original Dutch version.

No.	Question
Preparatory	
1	What is your position within NEN?
2	In what sector have you gained most standardisation experience?
3	How long have you worked for NEN?
Part one	
4	What does responsible standardisation mean to you as an employee of NEN?
5	What are reasons to standardise responsible?
6	What factors impede or obstruct responsible standardisation?
7	How can standardisation become more responsible?
8	Are you familiar with the terms 'Responsible Research and Innovation', 'Responsible Innovation', or 'Maatschappelijk verantwoord innoveren'[18]? If yes, could you please describe what these terms mean?
9	What is a successful standard according to you, and why?
Part two	
10	Inclusion in standardisation can be described as: "the active engagement of all stakeholders throughout the standardisation trajectory". On a scale from 1 to 5, how inclusive do you think standardisation is? Could you please motivate your answer?
11	What motivates inclusion in the context of standardisation?
12	What impedes inclusion in the context of standardisation?
13	What facilitates inclusion in the context of standardisation?
14	Is standardisation inclusive enough to develop successful standards, and why (not)?
15	Anticipation in standardisation can be described as: "the process that aims to foresee potential societal, economic, and technological impacts in early phases of the standardisation process". On a scale from 1 to 5, how anticipatory do you think standardisation is? Could you please motivate your answer?

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No.	Question
16	What motivates anticipation in the context of standardisation?
17	What impedes anticipation in the context of standardisation?
18	What facilitates anticipation in the context of standardisation?
19	Is standardisation anticipatory enough to foresee important societal, economic and technological impacts of the standard, and why (not)?
20	Reflexivity in standardisation can be described as: "the continuous evaluation of whether the goal, activities, and outcomes of standardisation align with their moral obligation to society". On a scale from 1 to 5, how reflexive do you think standardisation is? Could you please motivate your answer?
21	What motivates reflexivity in the context of standardisation?
22	What impedes reflexivity in the context of standardisation?
23	What facilitates reflexivity in the context of standardisation?
24	Is standardisation reflexive enough to develop socially desirable standards, and why (not)?
25	Responsiveness in standardisation can be described as: "a standardisation process that adequately changes standards based on the insights derived from the inclusive, anticipatory, and reflexive processes". On a scale from 1 to 5, how responsive do you think standardisation is? Could you please motivate your answer?
26	What motivates responsiveness in the context of standardisation?
27	What impedes responsiveness in the context of standardisation?
28	What facilitates responsiveness in the context of standardisation?
29	Is standardisation responsive enough to develop socially desirable standards, and why (not)?
30	Are there any remaining comments, remarks, or side notes that you would like to share?

C.2. An overview of Identified factors

This appendix gives an overview of the identified factors. Consultants indicated to which extent they recognized the factors by answering a survey: completely agree (1), partly agree (2), neutral (3), partly disagree (4), completely disagree (5).

Dimension	**Type**	**No.**	**Factor**	**Survey results[2] Median $(\bar{x})$**
Responsible standardisation	Motive	SM1	SDO's obligation to society	1 (1.41)
		SM2	Intrinsic motivation of SDO employees	2 (2.44)
		SM3	Out of committee members' own interest	3 (2.46)
		SM4	To safeguard the credibility of SDO	1 (1.63)
		SM5	To increase market acceptance	2 (1.78)
		SM6	To ensure the quality of standards	2 (2.33)
		SM7	To reach the Sustainable Development Goals (SDGs)	2 (1.81)
Inclusion	Motive	IM1	To increase the responsibility of standards	1 (1.58)
		IM2	To increase the market adoption of standards	1 (1.58)
		IM3	To increase the quality of standards	2 (2.19)
		IM4	To establish a standard that is perceived as logical/self-evident	2.5 (2.50)
		IM5	To increase the value of the SDO's stakeholder network	1 (1.58)
	Barrier	IB1	Unawareness of the process of standardisation	1 (1.62)
		IB2	Unawareness of the importance of participation in standardisation	2 (1.92)
		IB3	Difficulty of finding relevant standardisation processes	2 (2.24)
		IB4	Difficulty of being involved effectively	2 (2.04)
		IB5	The inequality in the influence which committee members have	3 (2.88)
		IB6	Lack of reflection on benefits a party might have gained through participation	2 (2.54)
		IB7	The limited time in which a standard needs to be developed	2 (2.12)
		IB8	A lack of a stakeholder's priority	2 (2.20)
		IB9	A lack of a stakeholder's interest	2 (2.33)
		IB10	The cost of involvement	1 (1.76)

Dimension	Type	No.	Factor	Survey results[2] Median $(\bar{x})$
		IB11	A lack of knowledge	3 (2.68)
		IB12	The stakeholder's assumption that they are not competent enough	3 (2.92)
		IB13	The technical nature of some standardisation processes	3 (2.56)
		IB14	The ambiguous role a stakeholder might have	3 (2.82)
		IB15	Resistance from other committee members	3 (2.88)
		IB16	The type of standard (e.g. formal standard, NPR, NTA, NEN-spec, etc.)	3 (2.38)
	Facilitator	IF1	Financial support for economically weak stakeholders	2 (1.83)
		IF2	Management of stakeholders' expectations	2 (2.13)
		IF3	Technology (e.g. virtual meetings, stakeholder feedback systems, etc)	2 (2.09)
		IF4	Non-membership forms of participation (e.g. public consultations)	2 (1.87)
Anticipation	Motive	AM1	To increase the responsibility of standards	1 (1.77)
		AM2	To increase the market acceptance of standards	1 (1.78)
		AM3	To increase the quality of standards	2 (2.04)
		AM4	To prolong the potential relevance of standards	1.5 (2.05)
		AM5	Intrinsic motivation of committee members	2 (2.55)
	Barrier	AB1	A lack of willingness to anticipate	2 (2.04)
		AB2	The composition of the committee	2 (1.91)
		AB3	A lack of technical knowledge	2 (2.39)
		AB4	A lack of financial resources	2 (2.30)
		AB5	A lack of skills to anticipate	2 (2.68)
		AB6	Unawareness of the current state of affairs	3 (2.68)
		AB7	Uncertainty of the outcome of standardisation	3 (2.65)
		AB8	The technical nature of some standards	2 (2.39)
		AB9	Uncertainty of how the standard will be used	2 (2.73)
		AB10	A lack or superficiality of anticipatory tools	2 (2.43)
	Facilitator	AF1	The inclusivity of standardisation	2 (2.00)

Dimension	Type	No.	Factor	Survey results[2] Median $(\bar{x})$
		AF2	Transparency of the committee's activities	3 (2.27)
Reflexivity	Motive	RM1	To increase the responsibility of standards	2 (1.82)
		RM2	To increase the market acceptance of standards	2 (2.05)
	Barriers	RB1	A lack of inclusion	2 (2.27)
		RB2	A lack of transparency	3 (3.00)
		RB3	Ambiguous interpretations of the SDO's rules/guidelines/code of conduct	3 (2.38)
		RB4	'Hidden' agendas or goals of committee members	2 (2.14)
		RB5	The complexity of the standardisation process	2 (2.19)
		RB6	The vast number of different standardisation processes	3 (2.71)
		RB7	A lack of impact assessments to reflect on a standard's impact	2 (2.55)
	Facilitator	RF1	SDO's regulation and guidelines	2 (2.27)
		RF2	Evaluation tools (e.g. customer feedback forms)	2 (2.19)
		RF3	Training of SDO employees (i.e. consultants)	1 (1.19)
		RF4	Controlling external bodies (e.g. ISO)	3 (2.77)
		RF5	Controlling internal bodies (e.g. policy committees, managers, etc.)	2 (2.41)
		RF6	Technology (e.g. customer platforms)	3 (2.82)
		RF7	External incidents	2 (1.95)
		RF8	A committee's awareness of its societal obligation	2 (2.05)
Responsiveness	Motive	ResM1	To make a positive societal impact	2 (1.88)
		ResM2	To address the SDGs	3 (2.67)
		ResM3	To create consensus	3 (2.43)
		ResM4	To increase the quality of the standard	2 (1.96)
		ResM5	To increase the market acceptance	2 (2.04)
		ResM6	To maintain the value of a standard	1 (1.43)
	Barrier	ResB1	A lack of clear requirements of when to terminate the process	3 (2.75)
		ResB2	Conflicting goals of committee members	2 (2.26)
		ResB3	'Hidden' agendas of committee members	2 (2.05)

Dimension	**Type**	**No.**	**Factor**	**Survey results[2] Median ($\bar{x}$)**
		ResB4	The complexity of the standard	2 (1.86)
		ResB5	The involvement of a party in a later stage	2 (2.32)
		ResB6	Reaching consensus becomes harder once a party is emotionally involved	3 (2.52)
		ResB7	Conflicting fundamental values of committee members	2 (2.43)
		ResB8	Some topics are less susceptible to consensus	2 (2.22)
		ResB9	Inclusivity (committee size impedes consensus	3 (2.36)
		ResB10	Dependencies on other SDOs (e.g. ISO, CEN, etc.)	2 (2.05)
		ResB11	The desire for technological stability (e.g. due to sunk investments)	2 (2.09)
	Facilitator	ResF1	The (partly) online meeting mode	2 (2.18)
		ResF2	A less formal type of standard (e.g. NTA, NPR, NEN-spec)	1 (1.76)
		ResF3	Governmental mandates for standard	2 (1.95)
		ResF4	Societal pressure	1 (1.68)
		ResF5	The severity of the problem at hand	1 (1.48)
		ResF6	The willingness of parties to compromise	1 (1.82)
		ResF7	A committee's group cohesion	2 (2.41)
		ResF8	Expectations of members (e.g. aligning goals)	2 (1.86)
		ResF9	The frequency of meetings	2 (2.00)
		ResF10	A sense of urgency	2 (1.95)
		ResF11	The context. The national context allows for more control	2 (2.27)
		ResF12	The sector affects the acceptable consensus and improvement speed	2 (2.24)
		ResF13	The mediating skills of chairpersons	2 (1.86)

C.3. An overview of the most prevalent identified factors

This appendix short lists which factors appeared most prevalent based on their median score.

Dimension	Type	No.	Factor	Results median ($\bar{x}$)
Responsible standardisation	Motive	SM1	The SDO's obligation to society	1 (1.41)
		SM4	To safeguard the credibility of the SDO	1 (1.63)
Inclusion	Motive	IM1	To increase the responsibility of standards	1 (1.58)
		IM2	To increase the market adoption of standards	1 (1.58)
		IM5	To increase the value of the SDO's stakeholder network	1 (1.58)
	Barrier	IB1	Unawareness of the process of standardisation	1 (1.62)
		IB10	The cost of involvement	1 (1.76)
Anticipation	Motive	AM1	To increase the responsibility of standards	1 (1.77)
		AM2	To increase the market acceptance of standards	1 (1.78)
		AM4	To prolong the potential relevance of standards	1.5 (2.05)
Reflexivity	Facilitator	RF3	Training of SDO employees (i.e. consultants)	1 (1.19)
Responsiveness	Motive	ResM6	To maintain the value of a standard	1 (1.43)
	Facilitator	ResF2	A less formal type of standard (e.g. NTA, NPR, NEN-spec)	1 (1.76)
		ResF4	Societal pressure	1 (1.68)
		ResF5	The severity of the problem at hand	1 (1.48)
		ResF6	The willingness of parties to compromise	1 (1.82)

Appendix D - Chapter 5

D.1. The Dutch Mission-oriented Topsector and Innovation Policy's missions per theme

This appendix provides an overview of all the 25 missions that are part of the Dutch Mission-oriented Topsector and Innovation Policy (Ministry of EZK, 2019).

Theme	Missions
Energy Transition & Sustainability	49% reduction of national greenhouse gas emissions by 2030, aiming for 95% lower emissions by 2050 compared to 1990.
	An entirely carbon-free electricity system by 2050.
	A carbon-free built environment by 2050.
	Carbon-neutral industry with reuse of raw materials and products by 2050.
	Zero-emission mobility of people and goods by 2050.
	A sustainable and completely circular economy by 2050, with resource use halved by 2030.
Agriculture, Water & Food	Reduction of the use of raw and auxiliary materials in agriculture and horticulture by 2030 and creating the maximum possible value from all end products and residuals by utilizing them as fully as possible (circular agriculture).
	By 2050, the agricultural and nature system will be net carbon-neutral (Joint mission with energy transition and sustainability).
	The Netherlands will be climate-proof and water-resilient by 2050
	By 2030, we will produce and consume healthy, safe and sustainable food, while supply chain partners and farmers get a fair price for their produce.
	A sustainable balance between ecological capacity and water management vs. renewable energy, food, fishing and other economic activities, where this balance must be achieved by 2030 for marine waters and by 2050 for rivers, lakes and estuaries.
	The Netherlands is and will remain the best-protected and most viable delta in the world, with timely future-proof measures implemented at a manageable cost.

Theme	Missions
Health & Healthcare	By 2040, all Dutch citizens will live at least five years longer in good health, while the health inequalities between the lowest and highest socio-economic groups will have decreased by 30%.
	By 2040, the burden of disease resulting from an unhealthy lifestyle and living environment will have decreased by 30%
	By 2030, the extent of care provided to people within their own living environment (rather than in health-care institutions) will be 50% more than today or such care will be provided 50% more frequently than at present.
	By 2030, the proportion of people with a chronic disease or lifelong disability who can play an active role in society according to their wishes and capabilities will have increased by 25%.
	By 2030, quality of life for people with dementia will have improved by 25%.
Security	By 2030, organized crime in the Netherlands will have become an excessively high-risk and low-return enterprise, thanks to a better insight into illegal activities and cash flows.
	By 2035, the Netherlands will have a navy fit for the future, which will be able to respond flexibly to unpredictable and unforeseen developments.
	By 2030, the Netherlands will have operationally deployable space-based capabilities for defense and security.
	Cyber security: the Netherlands will be in a position to capitalize, in a secure manner, on the economic and social opportunities offered by digitization.
	By 2030, the armed forces will be fully networked with other services and through the integration of new technologies, so that they can act faster and more effectively than the opponent.
	Supply and demand will come together more quickly to implement successful short-cycle innovations
	By 2030, security organizations will be capable of collecting new and better data, so that they are always one step ahead of the threat.
	By 2030, the role of security professional will be among the 10 most attractive professions in the Netherlands

D.2. Intensity: controls only

The statistical results for the variable intensity while using control variables only.

	(1)	(2)	(3)
	Multinomial logistic regression		
	Dependent variable: intensity (base level: 4. **No participation**)		
Variables	1. **Upstream participation**	2. **Midstream participation**	3. **Downstream participation**
TKI Agriculture & Food (1)	0	0	0
	(base)	(base)	(base)
Biobased Economy (2)	-14.73	-0.527	-0.465
	(2.160)	(0.846)	(4.545)
Chemical Engineering (3)	0.138	-15.82	-0.384
	(1.241)	(798.3)	(3.201)
Creative Industry (4)	1.715	0.160	16.58
	(1.262)	(0.747)	(2.396)
Delta Technology (5)	0.931	1.308***	-0.582
	(1.175)	(0.469)	(3.710)
Energy (6)	1.712	-0.248	15.37
	(1.059)	(0.518)	(2.396)
High Tech Systems & Materials (7)	-0.909	-1.802***	14.54
	(1.168)	(0.543)	(2.396)
Logistics (8)	1.582	-0.676	16.07
	(1.032)	(0.465)	(2.396)
Life Science & Health (9)	-14.63	0.989*	-0.172
	(2.173)	(0.567)	(4.485)
Maritime (10)	-0.538	-1.493**	0.222
	(1.429)	(0.715)	(2.979)
Horticulture & Vegetative Propagation (11)	1.531	1.513***	0.00727
	(1.256)	(0.521)	(4.785)
Water Technology (12)	0.841	1.486***	-0.803
	(1.246)	(0.480)	(4.502)
Start date	-0.462***	-0.158	-1.077***
	(0.179)	(0.125)	(0.395)
Constant	929.4***	316.4	2.155
	(360.6)	(251.8)	(2.525)
Observations / pseudo-R2		1,261 / 0.166	

Standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

D.3. Intensity: mission variable only

The statistical results for the variable intensity while using the mission variables only.

	(1)	(2)	(3)
	Multinomial logistic regression		
	Dependent variable: intensity (base level: 4. **No participation**)		
Variables	1. **Upstream participation**	2. **Midstream participation**	3. **Downstream participation**
Mission			
1. No mission	0	0	0
	(base)	(base)	(base)
2. Energy Transition & Sustainability	1.887**	1.769***	0.277
	(0.780)	(0.380)	(1.004)
3. Agriculture, Water & Food	2.430***	2.666***	-11.87
	(0.782)	(0.374)	(403.8)
4. Health & Healthcare	2.610***	0.668	1.478*
	(0.734)	(0.409)	(0.779)
5. Security	2.097*	1.286	2.096*
	(1.249)	(0.819)	(1.249)
6. Insufficient information	1.603	1.351***	-11.81
	(1.010)	(0.524)	(579.0)
Constant	-4.987***	-3.483***	-4.987***
	(0.710)	(0.338)	(0.710)
Observations / pseudo-r2		2,213 / 0.093	

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

D.4. Table 12: SBI-codes and organisation type

This appendix provides an overview of the organization types (including SBI-code) that returned in the project data.

SBI-code	Type	N
1	Agriculture and related service activities	164
2	Forestry and logging	1
6	Extraction of crude petroleum and natural gas	16
8	Mining and quarrying (no oil and gas)	3
9	Mining support activities	3
10	Manufacture of food products	48
11	Manufacture of beverages	2
13	Manufacture of textiles	9
17	Manufacture of paper and paper products	12
18	Printing and reproduction of recorded media	1
19	Manufacture of coke and refined petroleum products	47
20	Manufacture of chemicals and chemical products	137
21	Manufacture of basic pharmaceutical products and pharmaceutical preparations	43
22	Manufacture of rubber and plastic products	15
23	Manufacture of other non-metallic mineral products	18
24	Manufacture of basic metals	15
25	Manufacture of fabricated metal products, except machinery and equipment	53
26	Manufacture of computers, electronic and optical products	141
27	Manufacture of electrical equipment	47
28	Manufacture of machinery and equipment n.e.c.	199
29	Manufacture of motor vehicles, trailers and semi-trailers	14
30	Manufacture of other transport equipment	57
31	Manufacture of furniture	2

SBI-code	Type	N
32	Manufacture of other products n.e.c	24
33	Repair and installation of machinery and equipment	39
35	Electricity, gas, steam and air conditioning supply	35
36	Collection, purification and distribution of water	201
37	Sewerage	41
38	Waste collection, treatment and disposal activities; materials recovery	22
39	Remediation activities and other waste management	3
41	Construction of buildings and development of building projects	32
42	Civil engineering	69
43	Specialised construction activities	34
45	Sale and repair of motor vehicles, motorcycles and trailers	6
46	Wholesale trade (no motor vehicles and motorcycles)	407
47	Retail trade (not in motor vehicles)	10
49	Land transport	22
50	Water transport	19
51	Air transport	1
52	Warehousing and support activities for transportation	81
53	Postal and courier activities	3
55	Accommodation	2
56	Food and beverage service activities	5
58	Publishing	13
59	Motion picture and television programme production and distribution; sound recording and music publishing	2
61	Telecommunications	16
62	Support activities in the field of information technology	150
63	Information service activities	7
64	Financial institutions, except insurance and pension funding	572
65	Insurance and pension funding (no compulsory social security)	6

SBI-code	**Type**	**N**
66	Other financial services	10
68	Renting and buying and selling of real estate	16
69	Legal services, accounting, tax consultancy, administration	22
70	Holding companies (not financial)	205
71	Architects, engineers and technical design and consultancy; testing and analysis	383
72	Research and development	1,629
73	Advertising and market research	47
74	Industrial design, photography, translation and other consultancy	57
75	Veterinary activities	2
77	Renting and leasing of motor vehicles, consumer goods, machines and other tangible goods	40
78	Employment placement, provision of temporary employment and payrolling	17
79	Travel agencies, tour operators, tourist information and reservation services	2
80	Security and investigation	2
81	Facility management	7
82	Other business services	28
84	Public administration, public services and compulsory social security	290
85	Education	105
86	Human health activities	513
87	Residential care and guidance	3
88	Social work activities without accommodation	32
90	Arts	10
91	Lending of cultural goods, public archives, museums, botanical and zoological gardens and nature reserves activities	13
93	Sports and recreation	3
94	World view and political organisations, interest and ideological organisations, hobby clubs	320

Appendix E - Chapter 6

E.1. Q-statements

This appendix provides an overview of the statements used for the Q-methodology.

	No.	Statements
Problem-oriented	1	Circular construction provides lower particulate emissions than linear construction
	2	One of the goals of circularity in the construction industry is to reduce greenhouse gas emissions
	3	Circularity has the potential to contribute greatly to solving the nitrogen crisis in construction
	4	Circular construction addresses the problem of waste production
	5	With circular construction, we avoid the depletion of our earth
	6	The problem of linear construction lies mainly in the use of primary resources
	7	Circular construction is necessary to combat the decline of biodiversity
	8	Circular construction reduces the risk of water shortages in the Netherlands
	9	Circular construction helps reduce CO2 emissions to meet the Netherlands' climate goals
	10	With circular construction, we can reduce unnecessary material losses in the supply chain
	11	Circular construction benefits the water quality of the Netherlands
	12	Circular construction can prevent health damage by better handling toxic materials
	13	Circular construction can reduce the sector's energy consumption
	14	The core problem that circular construction addresses is environmental impact and climate change
	15	Circular construction contributes to reducing social inequalities in our society
	16	With circular construction, the industry’s supply risks of materials and components can be decreased
	17	Circular construction contributes to achieving a climate-neutral society
	18	Circular construction is primarily a means to reduce greenhouse gas emissions
Solution-	19	In a circular construction, down cycling of materials is inevitable
	20	Circular construction requires that a large portion of the materials used be bio-based
	21	Modular design is essential for circular construction
	22	The construction sector must focus on recycling to become circular

	No.	Statements
	23	A reduction in the use of primary resources must be a priority for circular construction
	24	The construction sector must commit to reusing components to become circular
	25	Circular construction requires new monitoring and measurement systems that can be used to manage circularity
	26	In order to realize a circular construction, suppliers and contractors must ultimately become responsible for assets over their entire life cycle
	27	Circular construction starts with thinking about how to use resources efficiently
	28	Material and design strategies should focus on the highest possible R-strategy on the "R-ladder
	29	Circular construction must focus primarily on extending the life of assets
	30	As-a-service business models play a key role in kick-starting the transition to circular construction
	31	A carbon tax is a crucial measure to accelerate the transition to a circular construction sector
	32	Future circular projects should focus on avoiding material use as much as possible
	33	Circular construction should focus on reducing waste production
	34	Circular construction requires that assets are designed for disassembly
	35	Material passports are necessary to realize circular construction
	36	New standards and guidelines are needed to facilitate circular construction
	37	In circular initiatives, more focus is needed on sustainable materials
	38	Circular construction should establish residual value based on the actual physical condition of assets rather than their depreciation period
	39	Circular construction requires substantial changes in current laws and regulations
	40	Climate adaptive building contributes to achieving circular construction
	41	Circular construction will need to focus more on the ‘cradle-to-cradle’ strategy
	42	Block chain can play an important role in making circular construction a reality
	43	A circular construction sector will have to strive to upcycle materials
	44	Procurement strategies are essential tools for achieving circular assets
	45	Reducing the material demand requires changes in our lives, for example by living smaller

E.2. List of respondents

This appendix is a list of respondents, including their actor (sub-)type and statistically significant factor loadings. 'No flag' denotes significant correlations of respondents with imaginaries other than their most fitting imaginary.

No.	Significant factor loading	Actor type	Sub-type	Job description of respondent
R1	1	Industry	Contractor	Department head sustainability
R2	1, 3 (no flag)	Industry	Contractor	Project manager sustainability
R3	2	Industry	Contractor	Chief commercial officer
R4	-	Industry	Supplier	Consultant
R5	3	Industry	Supplier	Manager
R6	3, 1 (no flag)	Construction clients	Public commissioner	Innovation consultant infrastructure
R7	3	Construction clients	Public commissioner	Consultant circular economy
R8	-	Construction clients	Public commissioner	Senior consultant circular economy
R9	1	Construction clients	Public commissioner	Technical manager
R10	3, 2 (no flag)	Construction clients	Public commissioner	Head of district
R11	1	Construction clients	Public commissioner	Senior consultant circular economy
R12	2	Construction clients	Public commissioner	Senior consultant circular economy
R13	3	Construction clients	Public commissioner	Asset manager
R14	2, 1 (no flag)	Construction clients	Public commissioner	Coordinator sustainability
R15	3 ,2 (no flag)	Construction clients	Public commissioner	Sustainability monitoring
R16	1	Construction clients	Public commissioner	Sustainability consultant
R17	1, 3(no flag)	Construction clients	Public commissioner	Transition director circular public spaces

No.	Significant factor loading	Actor type	Sub-type	Job description of respondent
R18	2	Construction clients	Public commissioner	Ambassador circularity
R19	2,1 (no flag)	Policy	Policymaker	Program secretary
R20	2	Researchers	University	PhD candidate circular construction
R21	1, 2 (no flag)	Researchers	University	PhD candidate circular construction
R22	1, 2 (no flag)	Researchers	University	Full professor
R23	1 ,3 (no flag)	Researchers	University	Assistant professor circular construction
R24	2, 1 (no flag), 3 (no flag)	Researchers	University	PhD candidate circular infrastructure
R25	1	Researchers	Research institute	Procurement expert dredging technology
R26	1	Advisory firms	Engineering firm	Lead engineer
R27	-	Advisory firms	Engineering firm	Director circular and bio-based solutions
R28	1, 3 (no flag)	Advisory firms	Engineering firm	Architect
R29	3	Advisory firms	Engineering firm	Business director circular economy
R30	3	Advisory firms	Engineering firm	Circular design manager
R31	2	Advisory firms	Consultancy	Consultant
R32	1	Infrastructure	Networks	Consultant sustainable construction
R33	2	Infrastructure	Networks	Manager
R34	-	Infrastructure	Banking	Business developer circularity

E.3. Factor arrays

This appendix provides an overview of the factor arrays

	No.	Statements	Factor 1	Factor 2	Factor 3
Problem-oriented	1	Circular construction provides lower particulate emissions than linear construction	-3	-1	-4
	2	One of the goals of circularity in the construction industry is to reduce greenhouse gas emissions	1	0	-1
	3	Circularity has the potential to contribute greatly to solving the nitrogen crisis in construction	-3	-2	-1
	4	Circular construction addresses the problem of waste production	0	-4	-2
	5	With circular construction, we avoid the depletion of our earth	5	5	3
	6	The problem of linear construction lies mainly in the use of primary resources	0	-2	1
	7	Circular construction is necessary to combat the decline of biodiversity	-2	-3	-2
	8	Circular construction reduces the risk of water shortages in the Netherlands	-5	-3	-5
	9	Circular construction helps reduce CO2 emissions to meet the Netherlands' climate goals	1	2	0
	10	With circular construction, we can reduce unnecessary material losses in the supply chain	1	1	2
	11	Circular construction benefits the water quality of the Netherlands	-5	-4	-4

	No.	Statements	Factor 1	Factor 2	Factor 3
	12	Circular construction can prevent health damage by better handling toxic materials	-1	-1	-3
	13	Circular construction can reduce the sector's energy consumption	-1	0	0
	14	The core problem that circular construction addresses is environmental impact and climate change	3	3	-1
	15	Circular construction contributes to reducing social inequalities in our society	-4	-4	-5
	16	With circular construction, the industry's supply risks of materials and components can be decreased	-1	-1	1
	17	Circular construction contributes to achieving a climate-neutral society	5	3	-2
	18	Circular construction is primarily a means to reduce greenhouse gas emissions	-2	0	-4
Solution-oriented	19	In a circular construction, down cycling of materials is inevitable	-1	-5	-3
	20	Circular construction requires that a large portion of the materials used be bio-based	-1	0	-3
	21	Modular design is essential for circular construction	0	4	4
	22	The construction sector must focus on recycling to become circular	-2	-5	-2
	23	A reduction in the use of primary resources must be a priority for circular construction	4	1	5
	24	The construction sector must commit to reusing components to become circular	1	3	3

	No.	Statements	Factor 1	Factor 2	Factor 3
	25	Circular construction requires new monitoring and measurement systems that can be used to manage circularity	0	3	5
	26	In order to realize a circular construction, suppliers and contractors must ultimately become responsible for assets over their entire life cycle	-4	-2	-3
	27	Circular construction starts with thinking about how to use resources efficiently	4	4	2
	28	Material and design strategies should focus on the highest possible R-strategy on the "R-ladder	3	5	1
	29	Circular construction must focus primarily on extending the life of assets	1	1	0
	30	As-a-service business models play a key role in kick-starting the transition to circular construction	-3	0	0
	31	A carbon tax is a crucial measure to accelerate the transition to a circular construction sector	0	2	-1
	32	Future circular projects should focus on avoiding material use as much as possible	2	1	0
	33	Circular construction should focus on reducing waste production	2	-3	1
	34	Circular construction requires that assets are designed for disassembly	0	4	4
	35	Material passports are necessary to realize circular construction	-2	2	3
	36	New standards and guidelines are needed to facilitate circular construction	2	-1	2

	No.	Statements	Factor 1	Factor 2	Factor 3
	37	In circular initiatives, more focus is needed on sustainable materials	3	-1	0
	38	Circular construction should establish residual value based on the actual physical condition of assets rather than their depreciation period	3	1	3
	39	Circular construction requires substantial changes in current laws and regulations	1	0	2
	40	Climate adaptive building contributes to achieving circular construction	-3	-3	-1
	41	Circular construction will need to focus more on the 'cradle-to-cradle' strategy	4	0	0
	42	Block chain can play an important role in making circular construction a reality	-4	-2	-1
	43	A circular construction sector will have to strive to upcycle materials	2	1	1
	44	Procurement strategies are essential tools for achieving circular assets	0	2	4
	45	Reducing the material demand requires changes in our lives, for example by living smaller	-1	-1	1

E.4. Factor Loadings

Factor loadings of respondents per factor. (X) denotes a respondents highest statistically significant factor loading.

No.	Factor 1	Factor 2	Factor 3	Actor type	Sub-type
R1	0.55151 (X)	0.22275	0.33380	Industry	Contractor
R2	0.54937 (X)	-0.03046	0.40704	Industry	Contractor
R3	-0.05025	0.48709 (X)	0.27687	Industry	Contractor
R4	0.30169	0.01773	0.13445	Industry	Supplier
R5	0.07233	0.12408	0.56173 (X)	Industry	Supplier
R6	0.42533	0.22807	0.59774 (X)	Construction clients	Public commissioner
R7	-0.08084	0.09090	0.45189 (X)	Construction clients	Public commissioner
R8	0.25379	0.36412	0.33996	Construction clients	Public commissioner
R9	0.63375 (X)	0.16557	0.02567	Construction clients	Public commissioner
R10	-0.00866	0.53135	0.54385 (X)	Construction clients	Public commissioner
R11	0.39299 (X)	0.27490	0.22987	Construction clients	Public commissioner
R12	0.23892	0.65721 (X)	0.27360	Construction clients	Public commissioner
R13	0.26348	0.06243	0.62832 (X)	Construction clients	Public commissioner
R14	0.39348	0.43647 (X)	0.12564	Construction clients	Public commissioner
R15	0.24948	0.38568	0.46627 (X)	Construction clients	Public commissioner
R16	0.65541 (X)	0.01612	0.18343	Construction clients	Public commissioner
R17	0.49496 (X)	0.24586	0.48728	Construction clients	Public commissioner
R18	0.19378	0.61395 (X)	0.07042	Construction clients	Public commissioner
R19	0.43198	0.56330 (X)	0.33155	Policy	Policymaker
R20	0.35224	0.59180 (X)	0.13472	Researchers	University
R21	0.55424 (X)	0.48054	0.00560	Researchers	University
R22	0.55052 (X)	0.40306	0.10487	Researchers	University
R23	0.53711 (X)	0.03574	0.41175	Researchers	University
R24	0.47150	0.50222 (X)	0.40131	Researchers	University
R25	0.60337 (X)	0.18742	0.24264	Researchers	Research institute
R26	0.66228 (X)	0.13766	0.08904	Advisory firms	Engineering firm
R27	-0.09326	0.18549	-0.0236	Advisory firms	Engineering firm
R28	0.54702 (X)	0.11916	0.48511	Advisory firms	Engineering firm
R29	0.20635	0.35942	0.48966 (X)	Advisory firms	Engineering firm
R30	0.28114	0.38166	0.41516 (X)	Advisory firms	Engineering firm
R31	0.21067	0.47160 (X)	0.23214	Advisory firms	Consultancy
R32	0.58548 (X)	0.10489	-0.18248	Infrastructure	Networks
R33	0.06040	0.53825 (X)	0.11735	Infrastructure	Networks
R34	0.37597	0.37512	0.02973	Infrastructure	Banking

About the Author

Martijn Wiarda was born on 7 September 1995 in Woerden, the Netherlands. He worked as a PhD candidate at the Faculty of Technology, Policy, and Management at Delft University of Technology (TUDelft) where he focused on Responsible Innovation for wicked societal challenges. Before his doctoral studies, he obtained degrees in mechanical engineering (BSc, 2017) and innovation sciences (MSc, 2019). In parallel, he worked as an engineer and army reservist for several years. He was a nominee for Utrecht University's Exceptional Extracurricular Achievement Award (2019) for promoting its regional entrepreneurial ecosystem.

During his PhD, he published in high-ranking peer-reviewed journals such as *Technological Forecasting & Social Change*, *Environmental Innovation and Societal Transitions*, and *Science and Engineering Ethics* and presented his work at several conferences, including EU-SPRI. In 2023, Martijn was also nominated for the CEN-CENELEC Standards+Innovation award (young researcher) for his research on Responsible Standardisation. He participated in two international PhD programs: 'Philosophy of Responsible Innovation' (2022) and 'International Doctoral Certificate in Responsible Innovation' (2023). Martijn spent six months abroad as a visiting scholar at the Institut d'études politiques de Paris, commonly referred to as Sciences Po (2022). He received the ISO Research Grant to identify potential needs for climate adaptation standards in response to sea-level rise (2022). Moreover, he supervised nine MSc thesis students and multiple research assistants and was part of two large European H2020 consortia being 'Co-Create Change in Research Funding and Performing' (Co-Change, ID 873112), and 'Participatory Real Life Experiments in Research and Innovation Funding Organisations on Ethics' (Pro-Ethics, ID 872441). In 2023, Martijn will continue his work as a postdoctoral researcher on Responsible Innovation and Mission Governance at TUDelft.

The Simon Stevin Series in Ethics of Technology is an initiative of the 4TU Centre for Ethics and Technology. 4TU.Ethics is a collaboration between Delft University of Technology, Eindhoven University of Technology, University of Twente, and Wageningen University & Research. Contact: info@ethicsandtechnology.eu

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Simon Stevin (1548-1620)

'Wonder en is gheen Wonder'

This series in the philosophy and ethics of technology is named after the Dutch / Flemish natural philosopher, scientist and engineer Simon Stevin. He was an extraordinary versatile person. He published, among other things, on arithmetic, accounting, geometry, mechanics, hydrostatics, astronomy, theory of measurement, civil engineering, the theory of music, and civil citizenship. He wrote the very first treatise on logic in Dutch, which he considered to be a superior language for scientific purposes. The relation between theory and practice is a main topic in his work. In addition to his theoretical publications, he held a large number of patents, and was actively involved as an engineer in the building of windmills, harbours, and fortifications for the Dutch prince Maurits. He is famous for having constructed large sailing carriages.

Little is known about his personal life. He was probably born in 1548 in Bruges (Flanders) and went to Leiden in 1581, where he took up his studies at the university two years later. His work was published between 1581 and 1617. He was an early defender of the Copernican worldview, which did not make him popular in religious circles. He died in 1620, but the exact date and the place of his burial are unknown. Philosophically he was a pragmatic rationalist for whom every phenomenon, however mysterious, ultimately had a scientific explanation. Hence his dictum 'Wonder is no Wonder', which he used on the cover of several of his own books.

Innovators are increasingly called upon to help resolve societal challenges such as pandemics, climate change, and social injustice. The complexity, uncertainty, and contestation associated with such wicked problems require them to leverage approaches that help navigate normative and epistemic considerations for decision-making. A large number of scholars and practitioners believe that the procedural approach of Responsible Innovation could offer this. Responsible Innovation aims to align innovations with societal values and worldviews through forms of anticipation, inclusion, reflexivity, and responsiveness. Early anticipatory and reflexive deliberations subsequently provide an understanding of what decisions and outcomes are deemed ethically acceptable in light of uncertainty. This dissertation explores the usefulness of some approaches applied by Responsible Innovation in tackling wicked problems. It suggests that Responsible Innovation paradoxically fosters collaborations while also revealing contestation, and that innovators will need to leverage boundary objects and combine complementary approaches to deal with the (multi-scalar) conflict that is attributed to societal challenges.

'Wonder en is gheen wonder'

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