Linnaeus University Dissertations
Nr 273/2017

Joacim Rosenlund

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Cross-sector knowledge production in environmental science

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Environmental research collaboration: Cross-sector knowledge production in environmental science
Doctoral dissertation, Department of Biology and Environmental Science, Linnaeus University, Kalmar, 2017

ISBN: 978-91-88357-55-7
Published by: Linnaeus University Press, 351 95 Växjö
Printed by: DanagårdLiTHO AB, 2017

Abstract

Rosenlund, Joacim (2017). *Environmental research collaboration: Cross-sector knowledge production in environmental science,* Linnaeus University Dissertation No 273/2016, ISBN: 978-91-88357-7. Written in English.

Increased interaction between science and society is recognised as one of the characteristics of contemporary science. Solving the complex environmental problems of our day also necessitate such interactions. In this thesis, theories of knowledge production and innovation, including the triple helix and Mode 2, were used to analyse and assess environmental science critically. The triple helix model claims that interaction between university, industry, and government, is essential for innovation development. The Mode 2 of science emphasises the social embeddedness of science. These theories of knowledge production are situated on a macro level. Most studies carried out about this have disregarded the interactions in practice between science and society. The aim of the thesis was to explore how these theories manifest themselves in practice. Further, the aim was to contribute to knowledge about cross-sector interactions in environmental research collaboration. Interactive research was conducted in three environmental research projects. One survey was also conducted on a national level. Results are distributed in five research papers. Firstly, the results showed that the triple helix became somethings else on a project level. Further, when working in a triple helix-based collaboration participants encountered boundaries and which could be crossed using boundary-spanning means. The use of dialogue arenas in interactive research, meaning research oriented workshops and seminars, aided both participants and the researcher to cross disciplinary and cross-sector boundaries. Solving environmental problems, using cross-sector research collaboration, necessitated the recognition of the collaborative process itself. An abstract environmental idea such as the circular economy was also found to contribute to bridging the gaps between research and society. Lastly, the research showed that environmental scientists reflect upon the relevance of their research. The scientists felt the need to provide society with relevant research and adjust their research choices due to this. This thesis ends up with a discussion about a Mode 3 of knowledge production where the democratisation of research is crucial. Here a fourth helix represents the further inclusion of society in general. A fifth helix includes the natural environment as a driver for collaboration, forming a quintuple helix which incorporates the environmental relevance into collaboration. This thesis contributes to knowledge about theories of knowledge production, cross-sector research collaboration and the role of environmental science in society.

Keywords

Triple helix; quintuple helix; Mode 3; cross-sector research collaboration; interactive research; boundaries; knowledge production; relevance of research; environmental science

Like it or not, for the moment the Earth is where we make our stand

Carl Sagan

Svensk sammanfattning

Den ökade interaktionen mellan forskare och det omgivande samhället anses vara karaktäristiskt för den samtida vetenskapen. För att hitta lösningar på de miljöutmaningar vi står inför krävs också ett samspel mellan olika samhällssektorer. I avhandlingen används teorier om kunskapsproduktion och innovationsskapande för att studera miljövetenskapens roll i detta. Triple helix-modellen menar att interaktionen mellan universitet, industri och offentlig sektor är viktig för att utveckla innovationer. Mode 2 å andra sidan lägger vikten på integrationen mellan vetenskap och samhälle. Dessa idéer beskriver på ett övergripande sätt en makronivå, vilket innebär att tidigare studier har till stor del bortsett från vad som händer i praktiken när man samverkar. Målet med avhandlingen är att undersöka hur dessa teorier ter sig i praktiken, hur väl de beskriver miljövetenskapen och hur samverkan mellan sektorer fungerar när representanter från de olika sektorerna arbetar för att lösa miljöproblem. Interaktiv forskning har använts i tre miljöforskningsprojekt. En enkätundersökning riktad till miljöforskare genomfördes också på nationell nivå. Resultaten visar först och främst att triple helix-modellen blir något annat på en projektnivå där makronivån tolkas av deltagarna. Deltagarperspektivet bör därför iakttas när triple helix används på en projektnivå för att hantera spänningen mellan makro- och mikronivåerna. När aktörer samverkar med triple helix som utgångspunkt träffar de på gränsdragningar men använder sig även av gränsöverskridande strategier för att ta sig över dessa. Dialogarenor, som används i den interaktiva forskningen, är workshops och seminarier som stödjer forskarna och deltagarna att ta sig över disciplinära och sektoriella gränser. För att lösa miljöproblem i sådana sammanhang behöver samverkansprocessen i sig uppmärksammas som komplement till de tekniska processerna. En abstrakt idé, såsom den cirkulära ekonomin, visar sig skapa utrymme för samverkan mellan forskning och praktik. Resultaten visar också att miljöforskare reflekterar över relevansen av sin forskning för samhälle och miljö och att denna reflektion påverkar deras val av forskning. I sin helhet kan avhandlingens kontext snarare beskrivas som en Mode 3 av kunskapsproduktion. Här är demokratiseringen och bryggan mellan forskning och praktik en viktig del. En fjärde helixsektor i form av samhället i stort kan därför inkluderas. Dessutom kan en femte helix, vilket bildar en quintuple helix, inkludera den naturliga miljön i sig som en drivkraft för samverkan. Denna avhandling bidrar med kunskap om teorier om kunskapsproduktion, samverkan över sektorsgränser och miljövetenskapens roll i samhället.

Preface

Scientists are not locked up in ivory towers isolated from the rest of society. Scientists influence and are influenced by the context that surrounds them. There are demands from society, or in other words a social contract of science, providing pressure on scientists to provide results that are beneficial for society. This is very clear when one considers the environmental challenges that our generation faces. Such challenges occur across all parts of society, and no single actor can find solutions to these. Collaboration is often required, with people working together to overcome differences and to create something larger than the sum of its parts. However, collaboration itself is challenging. There are also different theories and models of how science works and how it is supposed to work. While useful as frameworks for understanding, these are not always adequate to explain the everyday concerns of those that collaborate. In its most distilled form, this thesis seeks to explore how different people, from various parts of society, work together to solve environmental problems.

Acknowledgements

First and foremost I want to thank William for believing in me and my very different research process and approach to environmental science. You taught me that anything is possible and that things get better and better every day. Thank you Erik for all the good discussions and your support throughout the process, it would not have been possible without you. I also want to thank Anders for introducing me to interactive research, I hope you would have been proud of this thesis, which seemed so far away the last time I met you.

Thank you Henrik and Henric who proved to be awesome workmates and friends that made the long process much more fun and rewarding! Thanks to Fabio, Yahya, Eva, Amit, Lee, Marika, Jelena, Charlotte, Juris, Richard, Silvia and all others who have come and gone in the research group. It has been a pleasure to get to know you all! It has also been great to come in contact with the Brazilians and visit Brazil - Marcia, Alex, Tadeu, André and the rest of you.

Cheers to all of my university friends that have come and gone: Michelle, Jo, Alexis, Carina, Mireia, Håkan A, Anna, Håkan J, Anu, Kocken, Martin, Stephan, Emelie, Henrik - always good times! Special thanks to Christofer for helping me with all the zombies. To the ones who make university life possible: Ymke, Christina, Anna, Anders and Henrik - you guys are great. A special thanks to Per and Chayan who introduced me to wonderful Thailand at the end of my PhD.

I also had the opportunity throughout the research process to come in contact with those that really collaborate towards a better environment, namely: Ann-Christin, Bo, Lars, Anders, Björn, Karen, Åke, Jackie and all others - thanks for your wisdom. Thanks to Bo and Louise for good collaboration and cheers to Peter and Giangiacomo for their input and knowledge about statistics.

Thanks to Carl “Cartman” and Lena for artistic input. Thanks to old and new friends encountered along the way especially Max, Robban and Johan. I am also grateful for the funding from the European Regional Development

Fund making the first half of the research possible. I also value the funding from the faculty which made the second half possible.

Till slut vill jag också tacka min familj som alltid trott på mig och mitt intresse för studier. Min bror Marcus har format mig som person till stor grad. Jag tror att vårt gemensamma intresse för spel har lett till att jag blivit mer kreativ och bättre på att lösa problem. Min syster Nina hjälpte mig ut i världen och gav mig en språngbräda när jag flyttade till England både en och två gånger. Reslusten är kvar. Mor och far som alltid stöttat mig och trodde på mig redan när jag var runt och föreläste om bältdjur på mellanstadiet! Ni lade den bästa grunden för mig och därmed för denna avhandling.

Joacim Rosenlund
2016-11-16
Chiang Mai

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List of publications

The following publications are included in this thesis

I. **Rosenlund, J.**, Hogland, W., Johansson, A. W., Seddon, J. (2015). A cross-national environmental cluster collaboration: Shifting between an analytical and management level of triple helix. *Science and Public Policy*, 42 (4): 583-593. DOI: 10.1093/scipol/scu075

II. **Rosenlund, J.**, Rosell, E., Hogland, W. (2016). Overcoming the triple helix boundaries in an environmental research collaboration. *Science and Public Policy* (advance online publication). 1-10. DOI: 10.1093/scipol/scw045

III. **Rosenlund, J.** (2016) Improving regional waste management using the circular economy as an epistemic object. *Environmental Sociology* (ongoing revision)

IV. **Rosenlund, J.**, Rosell, E. (2016) Using dialogue arenas to manage boundaries between sectors and disciplines in environmental research projects. *International Journal of Action Research* (accepted)

V. **Rosenlund, J.**, Notini, P., Bravo, G. (2016) Exploring the attitudes to societal relevance: The effects on reflection and choice of research among environmental scientists. *Journal of Responsible Innovation* (ongoing revision)

Contribution of the author to the papers

Papers I, II & IV: The author had the main responsibility for the methodological set-up, fieldwork and writing. Analysis of the materials and parts of the writing were conducted together with the co-authors.

Paper V: The author had the main responsibility for the research design and writing. Data collection was done by author one and two. Authors two and three had the main responsibility for analysis.

The following texts are related to this thesis

Rosenlund, J. (2015). An Interactive Research Approach to the Triple Helix Model in Environmental Science. Kalmar, Linnaeus University. Licentiate thesis.

Rosenlund, J., Johansson, A. W., Hogland, W. (2014). Interactive Research in a triple helix Based Environmental Collaboration. In: Proceedings of triple helix XII International Conference - The triple helix and Innovation-Based Economic Growth: New Frontiers and Solutions. Tomsk, 11-13 September, 2014, Russia. 89-91.

Rosenlund, J., Hogland, W. (2014). Environmental collaboration in practice – Lessons learned from Kalmar. In: Proceedings of Linnaeus Eco-Tech 2014 - 9th International Conference. Kalmar, 24-26 November, 2014, Sweden.

Rosenlund, J., Hogland, W. (2012). Environmental practice and social scientific research in a triple helix platform. In: Proceedings of Linnaeus Eco-Tech 2012 - Proceedings of Linnaeus Eco-Tech 2014: 8th International Conference. Kalmar, 26-28 November, 2012, Sweden.

Rosenlund, J., Hogland, W. (2011). The triple helix model applied in the Kalmar region in Sweden. In: Proceedings of ECOBALTICA 2011 - The VIII International Youth Environmental Forum. Saint Petersburg, 29 September - 1 October, 2011, Russia.

Popular science articles

Rosenlund, J. (2015) Lämna slit och släng samhället. *Barometern* 151212

Rosenlund, J. (2015) En spännande forskarmiljö. *Barometern* 150911

Rosenlund, J. & Hogland, W. (2015) Nyckeln till god samverkan. *Miljö & Utveckling*, no. 5

1 Introduction

Collaboration has been a prerequisite for civilisation. It has made it possible to extract resources, produce advanced products and settle down across the world (Harari, 2014; Pagel, 2012). At the same time, this has caused much strain on the environment. Collaboration can hopefully also be a way to solve the environmental issues of our day (Gray and Stites, 2013). Setting up common goals for environmental improvement and fulfilling these goals by means of collaboration, is a powerful idea. While environmental scientists have considerable knowledge about environmental issues, the usefulness of this knowledge is extended when shared with sectors outside university. However, when non-university participants are brought closer to knowledge production, new challenges arises.

The research presented in this thesis concerns environmental science and its role in society, in particular when environmental scientists work together with sectors outside university. It has been argued that open forms of knowledge production are necessary to solve socio-environmental issues. This requires a well-functioning interaction between scientists and participants outside academia (Cornell et al., 2013; Cortner, 2000). Environmental issues do not consider the boundaries between sectors and the solutions to these issues require expertise from many parts of society. Collaboration is one *approach* to solving environmental issues. What happens when scientists collaborate with other sectors in society and does such collaboration live up to its promises? What is the consequence of a democratisation of science where the gap between research and society closes? This thesis aims to show how cross-sector collaboration and research/society interactions function in environmental science. This thesis will also show that collaboration creates challenges and that solutions need to address such challenges.

The studies presented in this thesis situate such cross-sector collaboration within *theories of knowledge production*. These theories of knowledge production include triple helix, quadruple helix, quintuple helix, Mode 2 and Mode 3. Such theories are ways to describe the current state of science, the emergence of innovations, and interactions between research and society.

While these could also be called theories (or models/ideas) of knowledge production *and innovation creation*, this thesis will stick to the term theories of knowledge production. The triple helix model emphasises that university, industry, and government interactions are necessary for knowledge production and innovation, while the Mode 2 idea emphasises the social embeddedness of knowledge (Etzkowitz and Leydesdorff, 2000). Mode 3 is a way to integrate several of these theories of knowledge production (Carayannis and Campbell, 2009). This thesis contributes to knowledge about how these theories of knowledge production are manifested in environmental science and cross-sector collaboration. In addition to this, the thesis presents a suggested way forward for studying and facilitating collaboration.

The idea of science as a social activity that influences and is influenced by society is not new (Longino, 2002). It has been argued that a new social contract of science is needed, where society entrusts the responsibility to scientists to help to solve the large scale environmental problems of our day (Lubchenco, 1998). To address these problems, scientists need to contribute to knowledge and communicate solutions to the public, considering both basic and applied research. This social embeddedness can be illustrated as an increased responsibility and focus on the relevance of research. The relevance of research is a term this thesis will explore further as this can be both a pressure to provide applied results and a perceived responsibility to approach problems in practice. Definitions naturally vary between contexts and disciplines. This brings another challenge which Bruno Latour referred to as sailing between two extremes where society engulfs science or science becomes isolated in itself:

> *Have we come all this way and escaped the Charybdis of 'science' only to be wrecked on the Scylla of 'society'?* (Latour, 1987, p. 175)

The different ways of fulfilling the social contract are discussed throughout the thesis using the theories of knowledge production. These theories provide a diagnosis on how science is conducted. One issue is that these theories are abstract and describe science on a macro level while collaboration itself takes place on a concrete micro level. This gap between macro and micro is illustrated in Figure 1. While it is possible to produce knowledge by directly targeting the natural environment, researchers are not isolated from the rest of society. Research collaboration can be interdisciplinary, transdisciplinary, international, between individuals and organisations, and so forth (Bozeman et al., 2013). Collaborative knowledge production is one way to close this gap and find solutions that are relevant and viable in practice.

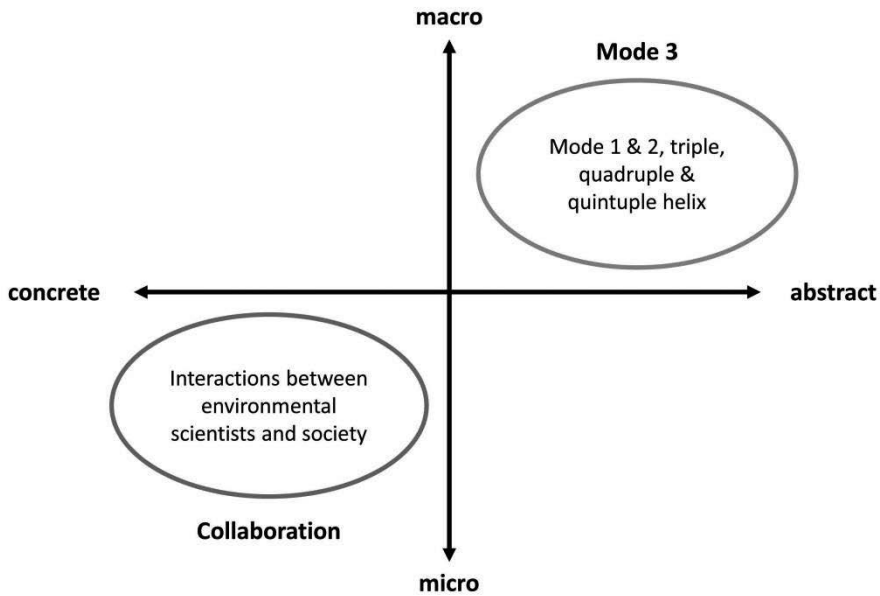

Figure 1. Situating theories of knowledge production in contrast to collaboration

This thesis acknowledges that the interaction between environmental scientists and other sectors is common. Further, that this interaction can be studied, and that there is a research gap regarding how the interactions between participants from different sectors work in practice. Such interaction also makes environmental scientists think about the relevance of their research and puts pressure on the scientists to perform research that can be used by the other participants. Further, this thesis explores a problem in practice as well as a methodological problem. The *problem in practice* is to understand the relations between the university, industry, the public sector and other participants in environmental collaboration. Studying such collaborations can give insights into how people can work more efficiently even though there are differences between sectors.

The *methodological problem* is how to study, and at the same time be part of a research team. For Latour, the making of science was more interesting to study than the refined end product. Accompanying scientist in this process of making and action is a way for social scientists to enter the "black box" of knowledge production (Latour, 1987). To open this black box, the studies conducted for this thesis have been carried out from the viewpoint of a sociologist. The author worked for more than five years in a research group in environmental science and technology, which meant that the author was an engaged scholar (Van de Ven, 2007), developing contacts and networks beyond the disciplinary boundaries and the university walls. Working in such

a way brings new challenges that traditional disciplines might not have the methods to take care of.

When involved in such work, the collaborators might not have the time or the tools to reflect on the collaborative process itself. Furthermore, collaboration brings another challenge, in which the collaborating partners want to see relevance and use for the end-results. This is where the social scientific point of view can help to document the thoughts of the participants in collaboration. This thesis intends to represent the input from a diversity of people, working in a multitude of areas, with the common goal to solve the environmental problems of our day.

1.1 Research problem, aims, and questions

The overall aim of this thesis is to explore how theories of knowledge production are reflected in practice. These theories include the triple, quadruple and quintuple helix models and Mode 1, 2 and 3. Such theories or ideas, can serve as frameworks to describe contemporary knowledge production and the role of science in society. This thesis explores how environmental science is situated within these frameworks of knowledge production. In particular, the thesis focuses on two characteristics of knowledge production namely: the collaborative aspects of environmental projects and the pressure on environmental scientists to produce research of relevance for society. This requires an insight into the everyday workings of cross-sector collaborations. This thesis presents some of the challenges of cross-sector collaboration but also suggests solutions. While each paper has its research questions and aims, shown in section 1.5, the main research questions that this thesis as a whole seeks to answer are:

- How does environmental cross-sector collaboration work in practice and how can interactive research be used to study and facilitate such collaboration?

- How can theories of knowledge production be used to understand environmental science?

1.2 Outline - The sum is larger than its parts

This thesis is a comprehensive summary of research conducted for five papers. Each paper presents its particular research questions and ideas. Three cases of collaboration have been studied with an interactive research approach to methodology. In addition to this, the methodological challenges arising from the cases are discussed in a fourth paper. Lastly, research is presented from a

study of environmental science on a national level, which shows how environmental scientists reflect upon their research.

The papers support each other and build upon the ideas of each other. While a summary of each paper is presented, the main purpose of the thesis is to put the papers in a wider context and connect them with previous research and theory. This is a way to create a synthesis of the five papers, presented in the conclusions and discussion, providing an added value. The goal is to provide insights that cannot be found in each paper by itself. The reader of this thesis is recommended to have these considerations in mind.

After this introductory section, the scope, gaps in the literature and research problem follows. The description of the context of the papers is then presented. After this, the two theoretical chapters are presented. The first concerns macro level ideas about contemporary knowledge production and the second present the micro-level theories of boundaries. The methodology and method chapters then follow. Finally, the thesis ends with the results, conclusions, and a discussion. **Appendix A** includes the questionnaire for **Paper I** and interview guides for **Papers I-III**. **Appendix B** provides additional information about the respondents, frequency distributions, methods, analysis and the questionnaire used for **Paper V**. After the appendices, **Papers I-V** are included in the printed version of this thesis.

1.3 Scope

Collaboration is a broad concept, and this thesis will focus on cross-sector research collaboration, which is the studied *phenomenon* in this thesis. Cross-sector collaboration includes interactions between a diversity of sectors and actors. Such collaboration brings questions about the relevance of research and the integration of science and society.

The *theoretical framework*, which helps to situate the studied phenomena, is the theories of knowledge production. As mentioned above these theories include the triple helix model, Mode 2 and Mode 3. These ideas have in common an increased emphasis on the relevance of research for society as well as increased interactions between university and other sectors (Hessels and van Lente, 2008). These theories of knowledge production serve as frameworks which contextualise the studies. A further theoretical framework is also provided by theories of boundaries which aid in explaining the micro-level of collaborations.

The *empirical context* is environmental science, which is where the collaborations occurred. Further, interactive research was the methodology, but also provided the empirical context by testing the theoretical frameworks from a pragmatic point of view. This also made it possible for the researcher to provide areas for empirical study including the meetings spaces in the form

of *dialogue arenas*. The phenomena, theoretical frameworks and empirical contexts, together form the framework of the thesis as shown in Table 1.

Table 1. Framework of the thesis

PHENOMENON	THEORETICAL FRAMEWORK	EMPIRICAL CONTEXT
• Cross-sector collaboration	• Theories of knowledge production • Theories of boundaries	• Environmental science

This thesis recognises that an interdisciplinary approach can contribute to studies of collaboration on multiple levels. As such, the thesis is useful for several disciplines besides environmental science, including studies of research policy, organisation and, science and technology. The goal is also to provide knowledge that can be used in practice to improve the interactions between science and society. The studies have been conducted on group, regional, national and international levels, depending on the paper; which is shown in the next section.

1.4 Background and research gaps

The objective of this section is to demonstrate previous research and the gaps in the literature that this thesis aspires to fill. While each paper targets specific gaps in the literature, this section shows the common gaps that mainly concerns the interaction between scientists and society by means of collaboration.

1.4.1 Previous research about cross-sector collaboration

Collaboration is often one of two things or a combination of the both: the best way to achieve goals or the only way to reach them. One of the key scholars of collaboration, Barbara Gray, viewed collaboration as a process of problem setting, direction setting and implementation: "*A process through which parties who see different aspects of a problem can constructively explore their differences and search for solutions that go beyond their limited vision of what is possible*" (Gray, 1989, p. 5). A process where a group of stakeholders interacts with each other to find solutions to a problem (Wood and Gray, 1991). This thesis supports this view of collaboration as a process.

> *Don't collaborate unless you are willing to thoughtfully consider and educate yourself about the nature of the process involved. Collaborating for collaboration's sake or to achieve only individual goals is likely to result in failure given the complexity of the collaboration process* (Thomson and Perry, 2006, p. 28)

The quote above also shows the importance of collaborators being involved with the process of collaboration itself. However, it is not always the case that participants are aware or interested in the collaborative process. Sometimes it is rather the end goals or other reasons that make participants collaborate. In this thesis, collaboration is used as a concept that summarises the interaction between sectors. The main focus in this thesis is cross-sector research collaboration, meaning collaboration between scientists and other participants outside the university. Cross-sector research collaboration has been encouraged by research policy as a means to produce knowledge of relevance and application to the wider society (Turpin and Fernández-Esquinas, 2011). Such collaboration was shown to provide new research results and a way to bring these results closer to application and society with the goal of solving environmental problems.

Various ways in which the university can collaborate with other sectors has also been identified: collaborative research, contract research and consulting. The level of such engagement has been related to both individual and organisational factors. Moreover, previous literature about the management of collaborations has relied on micro, macro and intermediate levels of investigation. The conceptualization of collaboration itself has also varied regarding the stages, models or success/failure of collaboration (Hibbert et al., 2008). Inter-organisational and multi-organisational collaborations have also been a subject to study, often in a public management perspective (Lowndes and Skelcher, 1998) and more firm oriented strategic alliances (Saxton, 1997; Das et al., 1998). These studies have been conducted in different disciplines and with different perspectives, including a diversity of sectors.

Studies have shown both positive and neutral outcomes for research and publication when collaborating (Perkmann et al., 2013; Boardman and Ponomariov, 2009). There were also findings that suggest that more intense collaboration improve research quality (Liao, 2010). Another example is a study of collaboratively written scientific papers which showed that these were more cited than single-authored papers (Beaver, 2004).

Further, different *reasons* for collaborating have been shown to create challenges for sustaining collaborations, as the goals and values can be different depending on the sector or type of partner (Ruuska and Teigland, 2009; Johansson, 2008b; Adler et al., 2009). Research on collaboration with firms and government agencies showed that reasons vary depending on the types of organisations academics cooperate with. Application of knowledge and financial rewards seemed to be important when collaborating with firms

while the collaboration with agencies was motivated by a general advancement of research. When both sectors were involved, application of knowledge seemed to be even more important (Ramos-Vielba et al., 2016).

Securing funds and performing academic research has been identified as reasons for university researchers to enter collaboration, while business opportunities were found to be less significant (Lee, 2000). While the university has been shown to be open to collaboration with industry, a fear of too close collaboration and loss of academic freedom has been noted as well (Lee, 1996). Other research has shown that the shift towards industry funding for research also imposes restrictions on scientists, mainly through means of restricted publications (Czarnitzki et al., 2015).

The good and bad of collaboration have recently been addressed as well. Identified factors for difficulties in collaboration were: different ways of working, autocratic management of collaborations, egotistical individuals, and commercial interests. However, findings also suggested that most collaborations were indeed working out well (Bozeman et al., 2015). While the study did not provide prescriptions for a better collaborative environment, it did point out that: "*a modest amount of participative group decision-making and a few but simple heuristics can make their collaborations run more smoothly*" (Bozeman et al., 2015, p. 15).

It has also been found that academics engagement with industry can be related to the expected *costs and benefits* of such collaboration. It was found that benefits are linked to the access of new resources and that costs are related to a reduction of researchers' autonomy. However, the secrecy of the results was not found to affect the decision among scientist to collaborate (Tartari and Breschi, 2012). Other *barriers* identified regarding academics interactions with industry include weighing the cost and benefits of collaboration and conflicts regarding disclosure and research topics. Researchers also seemed to collaborate in different organisational patterns ranging from bureaucratic to informal, participatory or even leaderless (Chompalov et al., 2002).

Trust was recognized as important for lowering these barriers (Bruneel et al., 2010) and trust improved with long-term interaction. Trust has also been found to be important when crossing these barriers between university and industry partners (Tartari et al., 2012). An evaluation of six university-industry collaboration projects concluded that universal factors such as trust and commitment are important (Barnes et al., 2002). It was also found to be beneficial if partners had prior experience of working together.

Stability, efficiency, and necessity have all been found to be important factors in university-industry collaboration. A predictable future environment to secure financial gain, funding, and business opportunities, were also found to be important factors (Ankrah et al., 2013). Cross-sector collaboration can include collaboration between government, business, non-profit organisations, communities and the public. One literature review concluded that such

collaborations were difficult to create and sustain. Awareness and appreciation of the differences between sectors and the surrounding environment have been identified as important success factors (Bryson et al., 2006). This review also acknowledged that interdisciplinary studies of collaboration are necessary in order not to exclude any significant facets.

The reasons for, and outcomes of, collaborations are diverse. There are some reoccurring themes regarding the barriers, or boundaries, between each sector and the importance of trust to cross these. For cross-sector collaborations, there are both advantages and disadvantages. The complexity increases when more partners are included, as in the difference between university-industry collaboration and triple helix collaboration. No matter what the structure of the collaboration is, both researchers, and participants from other sectors need to deal with these challenges on the micro level.

1.4.2 Gaps in the literature

When considering cross-sector research collaboration in organisational studies, there has been more written about the outputs from collaboration and its advantages than its disadvantages and less research about how these outputs emerge. There is a gap, a black box, in studies of collaboration especially regarding the real everyday grind of these. Individual initiatives for university-industry collaboration are less studied although it has been shown that personal arrangements support many university-industry interactions (Freitas et al., 2013).

If we turn to studies of research collaboration between the triple helix sectors some previous works are hinting to the research gap here. One study found out that extra coordination efforts are required especially when several universities collaborate (Cummings and Kiesler, 2005). Ideas about innovation creation like the triple helix, clusters and innovation systems have not informed how to support development in practice (Lundberg, 2013). Another shortcoming in the previous literature has been the lack of explanation of the mechanisms that led to successful three-part collaboration. The individuals that work in triple helix collaborations have rarely been the concern of research, though the effort has been made for example regarding the role of entrepreneurs (Brannback et al., 2008) and PhD candidates (Thune, 2010). As such there is a need to assess the individuals from each sector that works in such collaborations, from university, industry, companies and public sector.

While several organisations have claimed to be working in a triple helix (Laestadius et al., 2007), less research exists about how these processes begin and how they work. The ambition of this thesis is to gain more knowledge about these informal and personal arrangements as well as the everyday workings of such collaborations and factors leading to success and failure.

> *We do not know very much about this micro level and the processes at work since there have been few attempts to leave the macro level of analysis and get closer to the actual collaborators* (Melin, 2000, p. 32)

Melin for example studied these individual motivations. The individual reasons were found to include: access to data, competence, social reasons and other pragmatic reasons (Melin, 2000). There has also been a call for more research on a micro level to gain a deeper understanding of collaborative processes and everyday collaboration. These include institutional, cultural and trust based perspectives (Bjerregaard, 2010). Which were considered necessary to gain more knowledge about organising the intersections between the triple helix sectors.

> *Further research could thus address how central decisions ex ante and ex post collaboration are informed by varies types of collaboration strategies at the micro-level of the national triple helix* (Bjerregaard, 2009, p. 173)

Institutional factors have also been suggested to play a major role in how collaboration works. When micro-level interactions are considered, this would miss out on the background for many frustrations that come with collaborating (Rigg and O'Mahony, 2013). The macro ideas about knowledge production are situated on this institutional level. However, attempts of bridging the institutional macro level and the micro level of collaboration have been less developed.

A recent and extensive review of the literature of research collaboration identified several gaps in the literature, including the focus on either the individual researcher or the organisational level, failed collaborations, and studies focusing on citation rates and impact factors. Previous studies have focused less on the personal relationships between collaborators during the collaborative process. There has been a recognised gap in explaining the actual relationships between individuals in collaborations (Bozeman et al., 2013). In another state-of-the-art review of research collaboration, the authors ended up with a proposed research agenda: "*If one wanted more and better research on the impacts of complex boundary-spanning collaborations, how might one proceed*?" (Bozeman and Boardman, 2014). The authors then suggested that researchers would do best to rely on several informants "*with different roles and perspectives, from various components of the organization and to do this within all of the participating organisations*". Further, the authors suggested that research needs to avoid snapshots that only provide a short time frame. This thesis aims to provide a long-term view of cross-sector collaborative processes.

In the management literature, there has been a recognised gap between academic research and use of management strategies (Rynes et al., 2001). In turn, this is also a challenge related to the gap between scholars and practitioners. As such there is a need for methods and studies that bridge this gap between research and practice. In this thesis, an interactive research approach is used as a way to bridge this gap by creating dialogue arenas, such as workshops and seminars, where research and practice can meet.

Considering the theories of knowledge production such as triple helix, Mode 2 and Mode 3, there has been more written on an analytical macro level than on the individual micro level. The main reason is that these theories are concerned with macro scale change and institutional factors. At the same time, these theories aspire to explain the context where scientists work and conduct their everyday life. Collaborations between the triple helix sectors have mostly been studied on an analytical level, thus leaving the actual practice of such interactions largely unexplored. The research presented in this thesis will focus on the practice but still consider the theories of knowledge production.

Considering the relevance of research there has been a few studies that considered the reflection among the scientists (de Jong et al., 2015; Wahlbin and Wigren, 2007; Small et al., 2007). However, these studies have not connected issues on the micro level or delved deeper into understanding how such a trend affects the scientists. The relevance of research, sometimes framed as a rigor-relevance debate, has also been under-theorised in previous literature. The many and diverse factors that facilitate or impede relevance have seldom been studied (Fox and Groesser, 2015). The pressure to produce relevant research influences scientist, which is also considered in this thesis.

In summary, previous research about cross-sector collaboration has mostly been limited to university-industry research collaboration. When collaborating, participants reflect upon the expectations, conflicts, and solutions that this brings. Participants come from different organisations and have different backgrounds. Triple helix interactions are supposed to improve innovation and regional development. However, there are no instructions for using the associated analytical model when participants from different sectors are interacting with each other. The triple helix model was not developed for this purpose. In such interactions scientists also need to reflect and define the relevance of their research. The presented research will provide knowledge about cross-sector collaborative processes in practice.

1.5 Description of papers

This section presents a description of the five papers. The research has been carried out within the Environmental Science and Engineering group (ESEG) at Linnaeus University, in southeast Sweden, during the period 2011-2016. This was chosen firstly because the author was part of this organisation and research group. By being a social scientist in an environmental science context, it was possible to get access to projects and cases.

This empirical context was chosen because of the characteristics of the university and the region. Linnaeus University is the newest university in Sweden, formed by merging Växjö University and Kalmar Högskola in 2010. The university has initiated several entrepreneurial efforts including a liaison office, technology transfer office, and incubator. Further, environmental science and technology have been strong in the Kalmar region for some years, with a recognized cluster of activities related mainly to water management and technology. This is also a region of interest from a business perspective as there are considerable environmental technology exports from this area (Tillväxtanalys, 2012). The region also has the second most people employed in that sector compared with the number of individuals employed in the workforce (Strandberg et al., 2013). Furthermore, of the 39 cluster initiatives mentioned in a report on Swedish clusters (Nordensky, 2009), Sustainable Sweden Southeast AB (SSSE) is the only cluster mentioned from the Kalmar region. This is also one of the few clusters in Sweden focusing on clean technology companies. SSSE took part of the collaborations in **Papers I-III** in different ways.

In Table 2 a brief description of each paper is presented, along with the main research questions and hypotheses. In the following subsections, a description of the three cases is presented. Further, the contexts for the last two papers are presented as well.

Table 2. Description of papers and research questions

PAPER	BRIEF DESCRIPTION	RESEARCH QUESTIONS / HYPOTHESES
I	A case of international triple helix collaboration aiming to find innovative solutions to wastewater issues in olive oil mills.	How is the triple helix model used both on an analytical and a management level? What do participants make of the triple helix in their collaborating practice?
II	A long term case of regional university-industry collaboration aiming to improve wastewater management in the wood industry.	What challenges do actors from different sectors experience in practice when collaborating in a triple helix setting? What solutions to these challenges emerge from a common dialogue between these actors?
III	A small project team creating incentives for a circular economy by motivating industries and companies to improve their waste management.	How can the circular economy idea contribute to the practical improvement of waste management on a regional level?
IV	A critical reflection on the role of dialogue arenas during Papers II-III and how these bridge the boundaries between sectors and disciplines.	What boundaries does the interactive researcher encounter in environmental research projects? How can dialogue arenas be used to manage the boundaries that emerge within the research and practice systems?
V	Nationwide survey of environmental scientists/engineers in Sweden about their reflection on the societal and environmental impacts of their research.	H1: Most environmental scientists reflect upon the social and environmental relevance of their research; H2: The reflection upon this relevance influences the scientists' choice of research; H3: The degree of dissemination activities depends on the scientist' reflection about social and environmental relevance of their research.

1.5.1 Paper I: A cross-national environmental cluster collaboration: Shifting between an analytical and management level of the triple helix

The first case, presented in **Paper I**, was an international triple helix collaboration called STInno. This project included participants from five countries with three triple helix networks from Sweden, Finland, and Greece. Each of these triple helix networks had at least one participant each from university, company/industry, and public sector. Such a triple of the triple helix was a unique characteristic of the project. This project used the knowledge of the different sectors and countries to find solutions to wastewater issues in olive oil mills. Table 3 shows the participants in the project.

Table 3. Project consortia

COUNTRY (REGION)	RESEARCH	BUSINESS	PUBLIC SECTOR
Finland (Päijät-Häme region)	Lappeenranta University of Technology, Aalto University of Technology	Lahti Science and Business Park	Regional Council of Päijät-Häme
Sweden (Kalmar region)	Linnaeus University	Sustainable Sweden Southeast AB	Regional Council in Kalmar County
Greece (Western Greece region)	Foundation of Research and Technology of Hellas	Patras Science Park	Regional Council of Western Greece
UK	Lancaster University		
Italy	International Association of Mediterranean Agro-Industrial Waste		

This project provided an international perspective on cross-sector collaboration. The project included several meetings and workshops, both international and regional, over three years. In the UK, a workshop was arranged to discuss the triple helix model and what this meant for the project. In Greece, home to the olive mill wastewater issues, a meeting was arranged with representatives from different sectors as a culmination of the project. In

addition to the international meetings more spontaneous regional meetings were organised as well.

The paper aims to explain how the triple helix model was used during the project. The triple helix model was a guide throughout the project and was used by participants as a way to understand the collaboration on different levels. In doing this, it was necessary to study how the triple helix was used in practice by the participants both in the original sense of the analytical level of the triple helix model and on the management level of the triple helix.

1.5.2 Paper II: Overcoming the triple helix boundaries in an environmental research collaboration

The second case, presented in **Paper II**, had its starting point in a three-year research collaboration involving the University, a wood industry, and several other companies. This aimed to solve wastewater problems in the wood industry arising from process and stormwater sources. Researchers were working in close collaboration with industry partners to find solutions to these issues. This is shown in Figure 2 as the KK project.

This collaboration was extended for three more years to include additional participants in the Kalmar region. This is shown in Figure 2 as EU project. These participants included industries, companies, consultants, a business network, public sector representatives and other university partners. The research presented in the paper was conducted as a joint learning process where more participants were included throughout the project. In this way, it was possible to learn more about cross-sector collaboration and how participants perceived this.

Solving wastewater problems in the region also required an ability to disseminate this knowledge to society. Innovation and commercialisation processes were introduced to the researchers. Among these was the development of a treatment plant on site in the industry. Interactive research was used to initiate a dialogue about these processes and to encourage additional input from the various actors.

The paper aims to analyse the regional interactions between triple helix sectors in practice, to show the boundaries that exist between sectors, and how these can be crossed. **Paper II** uses a regional point of view and studies the process of moving from university-industry collaboration to include additional sectors. Further, this paper is also concerned with what happens on the research group level. This paper addresses the question of how the interaction between participants in cross-sector collaboration serves as an expression of the triple helix and even a Mode 3 of science. The challenges and possibilities of such collaboration are analysed focusing on sectors-specific ways of working. The difficulties and solutions that surface in such collaborative work are analysed in the paper.

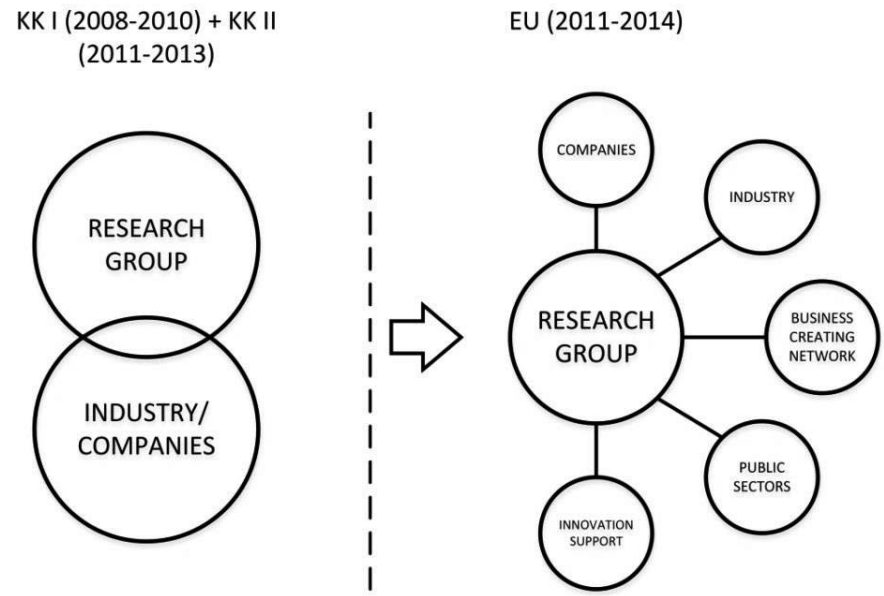

*Figure 2. Project structure (**Paper II**)*

1.5.3 Paper III: Improving regional waste management using the circular economy as an epistemic object

Third, the idea of approaching companies and industry with a circular economy was studied. Building on the previous studies, the idea was to critically discuss the circular economy as a concept among a broad range of participants including, but not limited to, the triple helix actors. The circular economy emphasises a move towards more sustainable consumption and production. In **Paper III** the study included a project team that bridged research and practice to influence industries, companies and municipalities on a regional level.

The project and the research were conducted in Kalmar region. For the project team, the main goal of the project was the production of a statistical database of waste and sludge in the Småland region. In addition to this, the interactive research methodology was used to facilitate and evaluate workshops. Further, study visits were conducted to organisations and companies in the region. Here the goal was to perform matchmaking where one organisation's waste could become another one's resource. A general improvement in the sorting and processing of waste was also a goal here. Table 4 shows the main activities that were performed during the project process, indicating the importance of the creation of meeting spaces, dialogue arenas, between research and practice.

*Table 4. Project activities (**Paper III**)*

ACTIVITY	TIME	PARTICIPANTS
Study visits to companies/industries and matchmaking	Throughout the project	-
Breakfast meeting	May 2015	25
Breakfast meeting and workshop	Oct 2015	15
Breakfast meeting and workshop	Feb 2016	31
Student workshop	April 2016	9

The project team consisted of one professor, one participant from a clean-tech business creating network and one statistician. The project team also included the interactive researcher in the project process. This meant that the author could study both the process and help to plan and conduct the workshops. These workshops, which worked as a way to connect the project team with other sectors in society, were evaluated by the interactive researcher. A key interest was to find out how the participants perceived the idea of a circular economy and if this could work as a gateway to introduce better waste management. In another sense, this was a knowledge-transfer between a triple helix inspired project team and other organisations.

The paper aims to explain how the idea of a circular economy can be used in waste management. Waste management was used as a way to focus the discussions about the circular economy. The creation of such spaces provided a practical implementation of the circular economy idea. This bridged the theoretical research with practice to provide incentives to improve waste management.

1.5.4 Paper IV: Using dialogue arenas to manage boundaries between sectors and disciplines in environmental research projects

Paper IV critically assesses the role of the interactive researcher in the research processes throughout **Paper II-III**. The interactive researcher crosses disciplinary as well as sector boundaries while studying cross-sector environmental collaboration. This paper considers the interactive research approach, in particular, the role of collaborative meeting places called dialogue arenas. Using these dialogue arenas the interactive researcher was able to identify and manage boundaries related to disciplines and sectors. It brings the lessons learned from two of the interactive research processes to a meta-level of analysis and provides a synthesis of these experiences. As such it provides a way forward for working with similar collaborations. The knowledge in this paper provides guidelines for future environmental collaboration, especially when integrating this with an interactive research approach.

The aim of this paper is to present a model for interactive research that highlights the role of dialogue arenas, particularly in environmental research collaborations. Two such ideal dialogue arenas are discussed, namely the seminar type and the workshop type. This paper highlights the challenge of being a social scientist in a natural scientist environment as this presents an additional boundary in the research system. In addition to this, there is also the cross-sector collaboration in the practice system to deal with. Dialogue arenas can be used in interactive research to manage the boundaries both in the research system and the practice system.

1.5.5 Paper V: Exploring the attitudes to societal relevance: The effects on reflection and choice of research among environmental scientists

Paper V puts the previous studies into a wider perspective of environmental science and engineering in general. Trends of increased interaction between sectors and demands for relevant research have both been identified. While **Papers I-IV** focuses on micro-level collaborative interactions, there are limits to the interactive research methodology. **Paper V** examines the idea of the relevance of research. This adds a quantitative dimension to study of how scientists' reflect upon the role of the relevance of research for society and the environment. A questionnaire was sent to environmental science and engineering research groups and centres in Sweden. As such, this paper concerns environmental science on a national level.

The aim was to gain knowledge about how scientists reflect upon the relevance of research and whether or not this had an effect on their choice of research. This study also helped to fill knowledge gaps that interactive research, with its micro-level action oriented approach, could not fill. Several variables were explored using the survey questions and with these variables two models were created. These models showed how different variables influenced the choice of research, reflection on relevance and dissemination activities. A textual analysis was also performed on the open question where the scientists reflected on the state of science and research.

2 From a triple helix to a Mode 3 of science

While each paper uses theory differently, there are theoretical frameworks that can link the papers together. There are different models and ways to create incentives for cross-sector collaboration. Some of these incentives are based on the already mentioned theories of knowledge production. This includes models that aim to explain how innovation is spurred on different societal levels. The triple, quadruple and quintuple helix models are such models. These theories give some ideas about how the interaction between the various sectors occurs or can occur ideally. Other theories describe or provide a diagnosis for contemporary knowledge production, how science functions nowadays and how it produces new knowledge. Science and technology studies aim to pinpoint what characterises contemporary science and how it evolved to this point. Mode 1, 2 and more recently 3, have been widely used concepts when debating contemporary science.

2.1 The triple helix model

Systems of innovation or innovation systems are one approach to studies of innovation and technological change (Edquist, 1997; Lundvall, 1992). A systems approach acknowledges the multifaceted nature of the innovation processes. A definition of an innovation system includes recognition of the importance of economic and institutional structures affecting learning and exploration and the interaction between relevant actors in this area. Regional innovation systems (RIS) are distinct from national systems (Cooke, 1992; Cooke et al., 1997). National innovation systems primarily involve large firms, while RIS also include small firms on a regional level. Regional industries and regional policy have an important role when linked to the interaction of private and public interests and specific formal institutions and organizations involved in knowledge and innovation development (Doloreux, 2003). Similarly, the theory of clusters refers to a geographically close group

of interconnected companies and institutions in a specific field (Porter, 2000; Porter, 1990). A cluster is a geographical concentration of specific industries benefiting from each other. Lately, new ideas about innovation creation such as innovation ecosystems, user-driven innovation, and living labs have all gained popularity (Arnkil et al., 2010). All these concepts mentioned above try to explain innovation and growth.

The triple helix is another perspective on the role of innovation in society. The starting point for the triple helix model in the research literature was the work of Henry Etzkowitz and Loet Leydesdorff (Etzkowitz, 2008; Etzkowitz and Leydesdorff, 2000; Leydesdorff and Etzkowitz, 1996). The model aims to provide a perspective on innovation and growth in which the interaction between university, industry and government institutions play key roles as shown in Figure 3. The collaboration between these three sectors is assumed to be a motor for innovation, with the university as the key sector and knowledge as a key ingredient. This assumes a move from a society where industry previously was the sector where innovations were created, towards a more knowledge-based society. The increased importance of a knowledge-based economy (OECD, 1996), recognises that world economies are increasingly dependent on knowledge and information, wherein universities take on increasingly important roles.

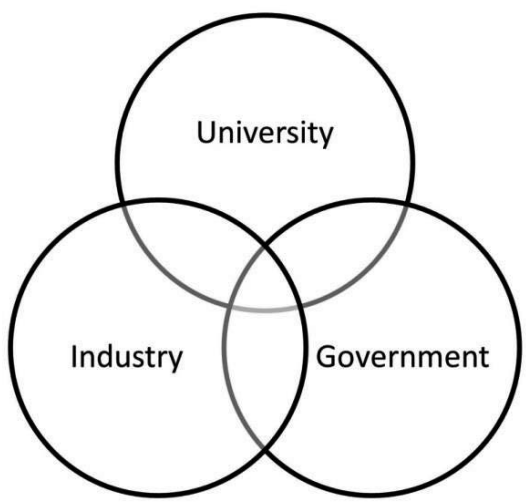

Figure 3: The triple helix model

Furthermore, the different triple helix sectors ought to solve problems and support each other in a collaborative manner. This means that a university may apply an entrepreneurial approach to its research and education, using incubators and close connections to science parks. University then becomes a major source of innovations. The industry will need to appreciate the value of

knowledge, research and education within their organisations. Finally, the government, or the public sector in general, can be the driver of this triple helix development, for example by financing universities, projects, and infrastructure.

When, or rather if, the borders between the three sectors merge, this forms an environment that supposedly becomes a growth ground for innovation. That is why the triple helix is said to be an evolutionary model as distinct from a linear one. The process of evolutionary innovation development means that both the innovators and the innovations are undergoing constant change and learning, thus constantly redefining each other, depending on what is researched (Nelson and Winter, 1982). In the long run, research that generates innovations becomes necessary to sustain the triple helix. The model suggests ways for innovation policy to support such interactions between sectors. Incubators, science parks, and risk capital ventures are examples of such support mechanisms.

One example is the idea of an entrepreneurial university (Etzkowitz, 2003b), where researchers and students are encouraged to commercialise, create firms and undertake entrepreneurial activities that lie beyond research and education. According to the triple helix model, an entrepreneurial university is a key player in transforming a region to a knowledge-based region (Etzkowitz and Klofsten, 2005). This includes ways to make knowledge relevant in the region, by the creation of firms and innovations, but also by integrating research and regional development. In turn, the region can even become an innovating region, where technological change and new firms are generated from the interaction between the triple helix sectors.

The triple helix model can be compared with the national and regional innovation systems. Compared with these two innovation systems, the triple helix does not restrict itself to any particular geographical level which allows for a broader range of analytical perspectives when studying such a model empirically (Leydesdorff and Zawdie, 2010). In a triple helix, innovations evolve by selection (market), stabilization (politics) and globalization (knowledge). Traditional innovation systems used the first two of these but have difficulty performing on a global level. Etzkowitz sees the national innovation system as a type of triple helix where the sectors keep their traditional roles. In a triple helix, the sectors become more interconnected through innovation processes (Etzkowitz, 2003a). Predicting where the innovation occurs is more difficult in a triple helix because of this interconnection.

2.1.1 The third mission and triple helix research policy

The idea of a third mission for universities was introduced into Swedish University law in 1997. Collaboration with the surrounding society was thus added to the two traditional roles of university namely education and research. The third mission in Sweden represents one aspect of increased integration

between research and practice (Brulin, 1998). The third mission puts emphasis on the role that knowledge plays in society. One report from the department of higher education (Talerud, 2000) acknowledged progress on this third mission but also challenges. Among these challenges were the lack of resources within the university and the lack of natural contact points for other sectors to reach the university sector. Two other reports from the department of higher education (Högskoleverket, 2004; Högskoleverket, 2008) show that the third mission might already be integrated into universities to the degree that it is no longer necessary to refer to it. In November 2016 the Swedish government presented the research policy bill "Collaborating for knowledge – for society's challenges and strengthened competitiveness". This serves as another example of how collaboration remains a part of the research policy discourse. However, such documents rarely tell about the actual challenges of collaboration.

The research funding agency VINNOVA (Sweden's innovation agency) got the mission to produce a model for measuring collaboration in Sweden. In addition to this, ongoing studies are concerned with providing an overview of how such collaboration has evolved and the role of research funding agencies in this. This has shown that universities have evolved strategies dealing with collaboration and intensified collaboration with other sectors. While previous collaboration was mostly based on individual initiatives, this took a more organized form during the 1990s. This was especially true for the newer universities that adopted this as a strategy (Benner and Sörlin, 2015; Åström et al., 2015). In other words, the collaboration between the university and other sectors is nothing new.

VINNOVA also played a key role in establishing the triple helix as a part of national research policy. VINNOVA influenced regional actors by steering regional policy using the triple helix idea (Fogelberg and Thorpenberg, 2012). By adopting and altering the model to suit its needs, the agency itself became an important player (Lavén, 2008). This is supported by additional research showing how Swedish triple helix policy was turned into practice (Lundberg, 2013). The triple helix and systems of innovation have become integrated into the narrative of policymakers and through this, the triple helix functions as a widespread and influential theory (Jacob, 2006). Research funding agencies shape the institutional elements of the university sector through the ways in which research is funded. This aids the institutionalisation of models such as the triple helix (Benner and Sandström, 2000). Later, the Vinnväxt program, advancing innovation and growth in Sweden through the agency of VINNOVA (Laestadius et al., 2007), led to an increased policy focus on innovation systems in Sweden. Vinnväxt is an example of how innovation system and triple helix perspectives are converted into policies.

When research funding agencies endorsed the triple helix model, top-down incentives for triple helix collaboration were created. The triple helix model then became *used as something else in practice* than originally intended. Research and development projects began to use the triple helix idea as an

approach vaguely based on the original model. For example, the government sector might be represented by a municipality or regional authority while industry might be synonymous with companies or the private sector in general. The empirical examples in this thesis represent such approaches to the triple helix. In these cases, the triple helix has become something else than originally intended, often implemented on a project level rather than a national level.

2.1.2 Limits to the triple helix

Before discussing the limitations and criticisms of the triple helix model, it is important once again to consider the original purpose of the model. The original intent was to provide a diagnosis for contemporary knowledge production where the role of universities for innovation development is emphasised. Still, the triple helix model has raised questions regarding the function of university when it leaves its traditional roles of research and education. It has been noted that increased pressure for intellectual property rights could take its toll on free research. It is necessary to consider what the changing roles of university mean in the long run (Leydesdorff and Etzkowitz, 1998). The changes that follow the transformation to an entrepreneurial university might even be met with resistance.

The challenges for the university might be underestimated in such a context. It is not certain that policy-driven collaboration between triple helix partners produces expected results (Hagen, 2002). The triple helix model promises a lot and it almost has an ideological agenda behind it. It sets high goals for development and provides less evidence that it, in fact, provides as promised. The triple helix has been disseminated as a positive narrative for management using the following normative considerations: economic growth can be managed, the three sectors are equal and independent but connected, and the three sectors are key for economic growth (Jensen and Trägårdh, 2004). When tested in practice, such a positive narrative can present high expectations that are difficult to fulfill.

Also, the model and function need to be studied more deeply. As previous research has focused on the three triple helix sectors, there has been a lack of research where civil society is included the model. Previous research has shown that the linkages between civil society and university through the dissemination of results, mutually beneficial partnerships, and socially relevant research, need to be considered (Copper, 2009). As the focus of the triple helix is innovation and social development, it has been argued that the model also can include civil society as a fourth helix. NGOs or social entrepreneurs could represent civil society here. These can be interesting actors that are quite different from firms because of their focus on social/environmental change as the main goal (Gawell et al., 2009). Suggested additions to the three sectors illustrate the complex reality of cross-sector collaboration beyond the three major sectors. The triple helix becomes a

model in practice that excludes and includes particular sectors, favouring established and strong partners.

An alternative is the inclusion of a fourth helix, thus forming a quadruple helix model. This aims to bring in marginalised groups which have been excluded from the triple helix idea. These groups can include civil society organisations or, as recognised by previous research, women as a group (Lindberg et al., 2014). While Leydesdorff does not limit the model to the three helices, he advises caution when specifying additional dimensions (Leydesdorff, 2012). When discussing these additions to the triple helix, it is also necessary to specify these additions.

2.2 A Mode 3 of knowledge production

Mode 2 is another perspective on the current state of science and knowledge production (Gibbons, 1994). The idea is that the original type of scientific research, called Mode 1, is often conducted within disciplines. In Mode 1, research is done in the academic context and subject to academic quality control where peer review is the most prominent form. Research here is done within disciplines and within the epistemological views and paradigms that exist within those disciplines. To conduct research in Mode 1 it means to adjust to the interest of the specific academic community.

It has been suggested that this original Mode 1 has shifted towards a Mode 2 of science (Gibbons, 1994; Nowotny et al., 2001). In Mode 2, science is more accessible for participants outside the university, and research is done collaboratively. The inclusion of different participants is one way in which the research can become more open. This also makes it possible for research to be conducted in networks, partly due to advances in information technology. The idea of an agora, an open forum for generating problems and solutions emphasises this social embeddedness (Nowotny et al., 2003). This means that knowledge production is not restricted to universities, and that there are a plethora of sites where knowledge is produced. Accordingly, researchers in Mode 2 need to reflect upon the societal relevance and accountability of the conducted research in relation to society.

Mode 2 is also characterised by transdisciplinary research (Hadorn et al., 2008) conducted in temporary teams, across disciplinary boundaries and with a range of perspectives including participants outside academia. This also means that Mode 2 is increasingly context-driven, and the focus on problem-solving is made possible by the increased interactions. In this view, the lines between applied and basic science are blurred. The usefulness of knowledge in society becomes a measure of success in this context. In practical problem-solving, it is reasoned; technical approaches are inadequate for finding solutions. While there is evidence that collaborative team-based research is the main mode of activity in the scientific community (Carayannis and Laget,

2004), the idea of Mode 2 is still open to debate (Bartunek, 2011). Table 5 presents the main characteristics of Mode 1 and 2 when compared with each other.

Table 5. Characteristics of Mode 1 and 2 (Hessels and van Lente, 2008)

MODE 1	MODE 2
• Academic context	• Context of application
• Disciplinary	• Transdisciplinary
• Homogeneity	• Heterogeneity
• Autonomy	• Reflexivity/social accountability
• Academic quality control	• Societal quality control

Most of the discussions about Mode 2 end up with the conclusion that this is an ideal model which coexists with Mode 1 on a continuum. Research in a Swedish policy context has shown that policy influences Mode 1 and 2, and that there has been an ongoing shift between Mode 1 and 2 (Hakansta and Jacob, 2016). This can be illustrated as a shift between basic and applied research and between science and sector driven research. It is likely that such a change, influenced by policy and research funding, can be found in several disciplines.

Etzkowitz and Leydesdorff rather consider Mode 1 as a new construct to highlight the autonomy of science. Compared with this, Mode 2 only confirms that science always has been organized in networks that solve practical problems (Etzkowitz and Leydesdorff, 2000). Triple helix, in this case, is a perspective from which to study the relations between these two modes. It has even been suggested there was a Mode 0 of science before Mode 1. Here science was conducted by the aristocracy, and private money was a key to this endeavour – and in some cases it still is (Bresnen and Burrell, 2013). Others have argued that Mode 2 and triple helix are just two of seven perspectives for studying contemporary science systems (Hessels and van Lente, 2008). Two common attributes were recognised from these seven perspectives:

- An increased emphasis on the societal relevance of research
- More interactions between science, industry and government

The increased interactions themselves seem to initiate the need for discussing the relevance in the first place. In this context, the role of universities and the other sectors is more flexible. This leads to greater opportunity for a university to participate in problem-solving; for example, through the triple helix approach. While a multitude of theories of knowledge production exists, together these provide a relevant, but incomplete, map trying to pinpoint where contemporary science is situated. This pluralism and coexistence of different perspectives have been referred to as a Mode 3 (Carayannis and

Campbell, 2009). The Mode 3 perspective recognises the diversity of ideas about knowledge production. Mode 3 is a perspective on the emerging innovation ecosystem of the 21st century where different theories of knowledge production such as Mode 1, Mode 2 and triple helix coexist. Mode 3 universities are knowledge environments that integrate Mode 1 and Mode 2 of knowledge with both applied and basic, collaborative and non-collaborative knowledge production (Carayannis and Campbell, 2014). Here the interaction between people, culture, and technology stimulate innovation across sectors. As in Mode 2, Mode 3 also considers the importance of the societal embeddedness of knowledge. Further, Mode 3 emphasises democracy as a growth ground for pluralism, knowledge, and innovation.

The already mentioned idea of a quadruple helix then adds a fourth helix to the triple helix model. According to Carayannis and Campbell, this fourth helix is the media- and the culture-based public, or society in general (Carayannis and Campbell, 2009). Culture, values, and the reality that media presents are considered real influences on innovation and knowledge. The inclusion of different actors and sectors would potentially result in a more democratic form of knowledge production. The quadruple helix is people centred in this regard and has a bottom-up approach (Lindberg et al., 2014; Copper, 2009). A shift from a triple helix to a quadruple helix includes stakeholders in the innovation process but the micro level approach to this model is still in its infancy (Miller et al., 2016). Further, Carayannis and Campbell mention the importance of creativity as essential for innovation. This also recognises inter- and transdisciplinary approaches to knowledge production and the importance of these for creativity and innovation (Carayannis and Campbell, 2014). This creativity means that innovation emerges bottom-up from concerns, such as environmental concerns not motivated by economic gains.

In addition to the quadruple helix, a quintuple helix has been proposed within the framework of Mode 3 (Carayannis et al., 2012). The quintuple helix, shown in Figure 4, adds the natural environment as a fifth helix. In doing so, culture and nature are integrated, which can help to facilitate a socioecological transition which is necessary to solve such environmental challenges. *Nature itself becomes a critical component in knowledge production,* assisting in the development of innovation and knowledge about sustainability. Environmental issues can create a potential for innovation and knowledge production. In other words, knowledge and innovation are created through the interactions between the five different helixes. These interactions can ideally lead to the inclusion of a green agenda or a more sustainable approach in all systems leading to positive inputs and outputs for the natural environment.

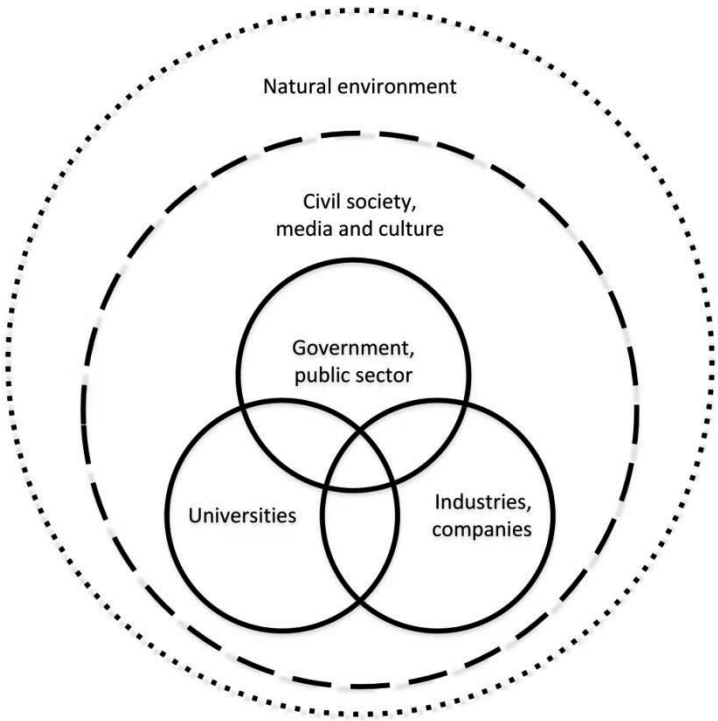

Figure 4. The quintuple helix model (based on Carayannis and Campbell, 2014; Carayannis et al., 2012)

This thesis acknowledges the increasing complexity of knowledge production as illustrated by the Mode 3 idea. Collaborative knowledge production can be present, in different ways, in all the levels of the quintuple helix model with a diversity of participants and contexts. In this view the emphasis should lie on inter- and transdisciplinary knowledge production. When including civil society or society in general, this contributes to a democratic form of knowledge production. While this thesis does *not* focus on the inclusion of civil society, it supports the inclusion of a diversity of participants in knowledge production processes. The main interest is what happens when the circles in the model (Figure 4) intersect with each other; that is when sectors collaborate with each other in practice. The inclusion of the natural environment is also an interesting point to make regarding environmental collaboration. Here the natural environment becomes the real target for knowledge production and the driver of collaboration, where the idea of an environmental relevance emerges.

2.3 Summing up

This thesis proposes that there are many different perspectives on knowledge production. The Mode 3 idea recognises that these various perspectives coexist and compete. Mode 3 can be used as a way to comprehend these complexities, not limiting these to any number of sectors or specifying which sectors are most important. Many of these ideas have noted that knowledge production is collaborative and performed in a societal context. These theories of knowledge production can be used as frameworks to understand environmental science and the role of cross-sector collaboration and the pressure from society and policy. While some of these ideas concern innovation development, innovation is not the focus of this thesis. This thesis will focus on the collaborative aspects that ideally would be the road to innovation.

It is also worth mentioning ideas that take a more critical perspective when describing contemporary science. One example of such criticism is the trend of academic capitalism. This illustrates the downside where an increased integration between markets and universities is recognised (Slaughter and Leslie, 1997). Increased competitiveness for funding and profit-related activities, like new firm creation and patenting, is likely to have an effect on the role of academics. The increased focus on publications in science and co-authorship has also been criticised. Another critical approach is the idea of a post-normal science (Funtowicz and Ravetz, 1993). This recognises the uncertainty of scientific claims especially regarding environmental issues and risks. For this reason, the proponents of this approach suggest that knowledge production needs to be democratised. The idea is that the results ought to be validated by the larger society that is affected by the issue at hand.

This leaves us with questions of how this framework of the triple, quadruple or quintuple helix and Mode 1, 2 or 3 are manifested in practice and how well these describe practice. There is less research about how these ideas are manifested in actual collaborations. To study this, it is necessary to connect macro level perspectives to the everyday micro practice of cross-sector collaboration. The next chapter presents a theoretical framework that provides the tools to do this.

3 Theories of boundaries

While the previous chapter introduces theories of knowledge production, this is not enough to critically study and analyse the process of collaboration. To do this, the theoretical perspective of boundaries is used, in particular for **Papers II-IV**. A boundary consists of different demarcations and activities that limit an area. These limits include numerous ways in which sectors, are distinguished from each other by knowledge, spatiality, identity, interaction, culture, occupation, and discipline (Hsiao et al., 2012). Such boundaries are sociocultural differences that give rise to discontinuities in interaction and action (Akkerman and Bakker, 2011). In this thesis, the studied boundaries include firstly those between sectors, secondly, between disciplines and thirdly between research and society. The demarcation between different domains can lead to difficulties in communication. This is a problem of managing different types of knowledge, and such communication can evolve through collaboration.

Knowledge production is manifested in practice as a crossing of boundaries between sectors. Further, this can also manifest itself as a crossing of the divide between research and society, between basic and applied science and between disciplines. The interactions between university and society bring with it the challenge of collaborating cross boundaries (Turpin, 1999). In general, knowledge and practice need to be integrated when solving environmental issues which necessitate crossing boundaries between knowledge and action (Cash et al., 2003). Differences between sectors emerge most prominently when these interact with each other. This happens in collaboration and other arenas where the sectors meet.

3.1 Knowledge management across boundaries

An important skill when collaborating is the ability to share knowledge across boundaries. In research projects, the main aim is to increase the understanding of the problem in a scientific way. However, to satisfy the information needs of other collaborative partners, scientists need to transfer the knowledge.

Alternatively, other collaborators with similar knowledge can help with the translation and transfer. Vice versa, there may be technical or local knowledge that partners from the other sectors need to translate to the scientists. The transfer of knowledge is, therefore, a two way (or many-way) process. A theory of knowledge management can help to understand this process.

The framework of Carlile (Carlile, 2004) concerns such knowledge management. This framework can also be used to study how researchers communicate with and cross boundaries between research and practice, between disciplines and, between sectors and communities (Van de Ven, 2007). It can also help to answer how knowledge is used and translated. For example, when such knowledge is being disseminated to society and utilised by a variety of actors outside academia. The key for such a communication between different communities is to have a common knowledge of the structure, meaning, and use of the language. Transferring knowledge cross boundaries becomes challenging when differences, dependence, and novelty of knowledge increases. This process requires numerous interactions and involvement between the collaborators.

As illustrated in Figure 5, Carlile suggests (Carlile, 2002; Carlile and Rebentisch, 2003; Carlile, 2004) that there are different communities in an organisation, and each of these possesses a unique and specialised knowledge. When crossing these knowledge boundaries between communities, it is necessary to consider differences in knowledge, the dependence between people, and the lack of common knowledge, when introducing a novelty into the organisation. Knowledge ***transfer*** (1 in Figure 5) is fundamental for processing information across a ***syntactic boundary***. Problems can occur when codes, routines, and protocols do not function and lead to a breakdown in knowledge transfer. Solutions to this include a common lexicon or standards that facilitate the sharing of information. Here individuals serving as specialists can help to facilitate the transfer.

Each community that collaborates has different ways of working reflected in their culture. Particular values and norms are often implicit and sometimes irrational. These can seldom be shown in written form but can be learned and can lead to differences in meaning, assumptions, and views of the context forming a ***semantic boundary***. A solution here is to form a common or shared meaning. This occurs through negotiation and the development of a common story, the use of boundary spanners and boundary objects. These means bring people together around a hub of knowledge that allows people to learn about each other's communities. As such this is referred to as a process of ***translation*** (2 in Figure 5) between different cultures. Such translation is particularly necessary when novelty enters the organization.

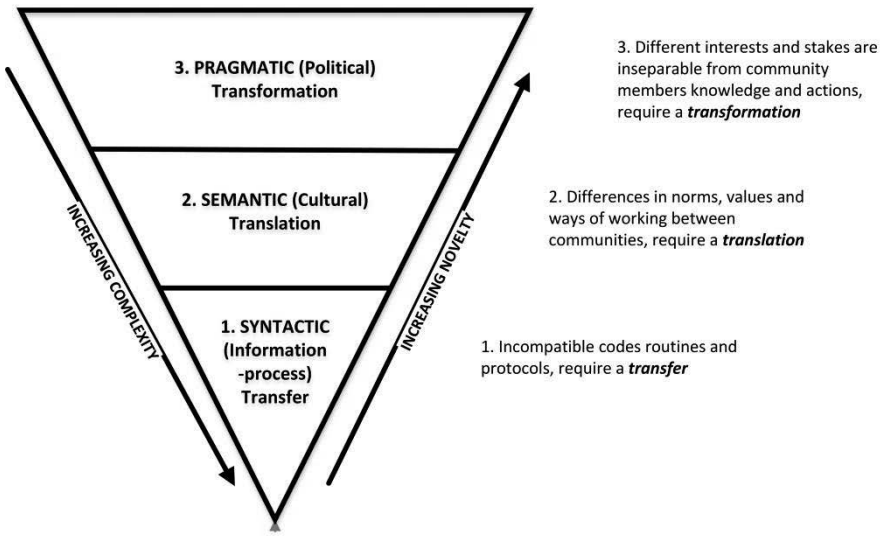

Figure 5. The integrative framework for managing knowledge across boundaries (based on Carlile, 2004)

If such novelty results in different interests, this necessitates a ***transformation*** (3 in Figure 5), making it possible to cross the ***pragmatic boundary***. Each community has something at stake, and the interest and actions cannot be separated from the community members' knowledge. These communities can also be sectors that have different ways of doing things and might oppose the transformation of knowledge. Solving this problem require an investment in relations, networking and ways to learn about each other's differences. While time-consuming, the facilitation of common areas, such as dialogue arenas, can help to create such common ground. Boundary objects (subsection 3.2 below) can be a common model or idea that helps with this transformation.

In Table 6 the three boundaries are presented, including the main problems and solutions that can be related to these. As an alternative, it has also been suggested that the syntactic boundary can be a called information-process oriented boundary. Further the semantic can be regarded as a cultural boundary and the pragmatic a political boundary to emphasise the processes as work here (Kellogg et al., 2006). These terms are used in **Paper II** for the purpose of describing the collaboration between triple helix sectors.

*Table 6. Framework for managing knowledge across boundaries (**Paper II**)*

BOUNDARY	PROCESS	PROBLEM	SOLUTION
Syntactic (information-process oriented)	Transfer	Incompatible codes, routines, and protocols leading to a breakdown in knowledge transfer	Common lexicon, or an individual permitting the sharing/translation of information across communities
Semantic (cultural)	Translation	Differences between communities' understanding of the area due to their norms and values / Knowledge situated in practice	Common and/or shared meanings developed by negotiating agreements and objects
Pragmatic (political)	Transformation	Each actor brings their own way of doing things and their own knowledge inseparable from interests and actions	Adjust some of the existing knowledge to the other actors / Build relationships and common interests through practical and political effort

3.2 Ways to cross boundaries

This section will consider the different ways to cross these boundaries in more detail. Boundary-spanning means finding solutions to problems of working between and within organisations where different communities, or sectors, collaborate and manage knowledge. In this section, the boundary spanning function of activities, organisations, individuals, and objects will be considered. These can aid in the transfer, translation, and transformation of knowledge and help to facilitate collaboration.

3.2.1 Boundary-spanning activities, boundary organisations and boundary spanners

Previous research has identified different activities that can help crossing and span boundaries (Ancona and Caldwell, 1992; Drach-Zahavy, 2011). These activities range from ambassadorial strategies that communicate progress and

knowledge with the external environment, to more isolationist strategies that avoid releasing any such information. Scouting for information and seeking other advantages are other such activities. Later research identified three main categories of boundary-spanning activities (Curnin and Owen, 2014). The first category is collaboration, which includes the ability to represent, communicate, network and enable activities. The second category is skills, including the management and analysis of information and the coordination of resources. The last and third category is knowledge both within the organisation and knowledge about external organisations.

Theories about team boundary-spanning focus on activities where teams interact with external parties (Marrone, 2010). Representation is one important activity here, meaning ways of persuading others, requesting resources and protecting one's group. In team boundary spanning it is also important to coordinate the work with others in different ways. Here it is also important to search for information by gaining input from the outside for information or expertise.

Boundary-spanning activities need to consider the experiences of people that encounter the boundaries. Learning processes are proposed as an important part of this in the way boundaries are identified, constructed and transcended. The goal of these is to create continuity when confusion arises due to sociocultural differences (Akkerman and Bakker, 2011). On the other hand, boundaries help individuals to simplify and order their environment (Ashforth et al., 2000; Fonner and Stache, 2012). Consider for example the boundary between public and private sector, if that didn't exist that would create issues of legislation and identity. On the other hand, such boundaries do complicate boundary-spanning.

Boundary-spanning occurs both on the individual and organisational level (Friedman and Podolny, 1992). Organisations that mediate between science and policy are referred to as boundary organisations (Guston, 1999). Such organisations provide a space for a common understanding and communication across science and policy domains. In doing so, boundary organisations can bring together participants from different domains. A boundary organization needs to be able to speak to and face all audiences (Guston, 2001). In constructing these boundary organisations, the development or boundary objects can help bridge differences between actors (Hellström and Jacob, 2003). Boundary organisations within universities can also form important links between science and environmental policy (Parker and Crona, 2012).

In addition to organisations, the literature on boundary spanners considers individuals that functions as bridges or facilitators between groups of people or organisational worlds. These individuals have different roles and different ways that they perform this boundary-spanning in practice. Boundary spanners cross physical and cultural boundaries by occupying key positions (Long et al., 2013). These can serve important functions by filling in what has been

called structural holes, meaning unoccupied positions in networks (Burt, 2005). Boundary spanners are important to stimulate innovation, transfer knowledge and build up trust cross boundaries. They can resolve conflict and strengthen bonds between actors. On the downside, such boundary spanners can experience too much responsibility when fulfilling their role (Long et al., 2013).

Individuals can act as boundary spanners by being brokers and translators (Pawlowski and Robey, 2004). Brokers communicate between different communities that need to understand each other and be coordinated. Translators use ways to explaining the worldview of one community using the terms established in another community. The aim of this process is for communities to understand each other's language. Individuals can serve as gate-keepers and liaisons that have specialised boundary roles (Tushman, 1977). Research about skills that are useful for boundary spanners has found four different roles of the reticulist, entrepreneur, interpreter and organizer (Williams, 2011). Furthermore, social scientists and science and technology scholars, in particular, can be effective boundary spanners between science and policy (Webster, 2007). Working in other areas means that the boundary spanner needs to learn the terminology to help with the translation and transfer of knowledge.

3.2.2 Boundary objects

In addition to individuals and organisations, there are also boundary objects. These are concrete or abstract objects that serve boundary-spanning functions. When involving a diverse group of actors, there is a need to create a common understanding. Boundary objects sit between domains and can be understood and used by each domain: "*scientific objects which both inhabit several intersecting social worlds […] and satisfy the informational requirements of each of them*" (Star and Griesemer, 1989, p. 393). Abstract or concrete, these have some form of common structure recognizable to all communities while the meaning of them can be diverse. Examples of boundary objects include repositories (library, museum), ideal types (diagram, atlas), coincident boundaries (geographical area) and standardized forms (lists). In its abstract form, a boundary object is rather a representation of an idea that is used by the different communities. Different communities may share a common goal, such as the improvement of the environment, which provides a common structure for the participants.

The interpretative flexibility of such objects has been the main focus of researchers. Two other aspects of material/organizational structure and the scale/granularity have been less discussed. It has been suggested that the organizational level would be the most appropriate scale. All these ought to be taken into consideration as such objects allow for collaboration even when there is no consensus (Star, 2010). In this way, boundary objects can be used

to facilitate collaboration. Boundary objects serve as another way to span the boundaries between different communities:

> *Observing individuals in practice and focusing on the objects they work with and the ends that they pursue provides a concrete delineation of what to observe and what to compare in terms of how knowledge is created and structured.* (Carlile, 2002, p. 446)

Sometimes the boundary object that is supposed to be an effective means of communication between groups fails because of its complexity, which means it is an ineffective boundary object. It can be used as a way for an occupational group to solidify its status if it is the only group that has an understanding of it. However, a boundary-spanning group of people could help translate this (Bechky, 2003). For example, it has been suggested that the borders between the triple helix sectors can be boundary objects, used by actors to uphold the sector specific interests (Metcalfe, 2010).

Another concept similar to boundary objects is epistemic objects. These are abstract by definition and open to interpretation. As such, these can exist solely as an idea. These have an evolving ontology, and the definition depends on the situation and use of the object (Ewenstein and Whyte, 2009; Nicolini et al., 2012) and often demand further inquiry by those that pursue and use them. Such objects are continuously evolving, and the definition might vary over time.

Scientists use epistemic objects and can modify them or eliminate them depending on their usefulness (Chang, 2011). The object might have had impact and meaning at one point in time, only to be forgotten later on. In **Paper III** the circular economy is seen as such an epistemic object which is discussed by participants as an idea, compared to the concrete application in waste management. Still such an environmental goal, even as an idea, can contribute to collaboration and provide a framework to work within.

It has also been claimed that individuals can be active boundary subjects, rather than passive boundary objects, highlighting the role of change and the political role of such individuals (Huzzard et al., 2010). Action researchers can be such subjects, making connections using dialogue and conversation. In doing so, researchers construct new relations, actor conceptions and ways of working, transgressing boundaries across organisations. Boundary spanning actors have connections and networks that bridge gaps between people and sectors, developing interpersonal relationships.

Action- and interactive researchers can help with the creation of common dialogue arenas which can aid in the crossing of boundaries between sectors, disciplines and between research and society. In such dialogue arenas, common environmental issues can be discussed. The next two chapters about methodology and methods will consider this.

4 Methodology: Action research and interactive research

This chapter presents the methodology for studying collaboration while being a part of it. It has been argued, when knowledge production is not limited to the university, that new forms of research are needed to answer society's questions (Tydén, 2002). There is also a tension between the university characterized by free science, and the necessity to collaborate with the rest of society through applied scientific means.

Action research is helpful in managing tensions between theory and practice, and between research and society. In this methodological tradition, it is argued that the researcher need to work together with other participants in a collaboration to produce new knowledge (Gustavsen, 2003). Studies of collaboration can benefit from an approach where the researcher is situated close to the participants and when the researcher is a part of the organisation (Huxham, 2003). Problems and solutions that occur in the collaboration can then be picked up by the researcher and analysed. The following sections address the pragmatic foundations of action research leading to the adoption of an interactive research strategy. The methodology provides the tools for studying collaboration and creating spaces for collaboration. This methodology section is relevant for **Papers I-IV** but less so for the quantitative study in **Paper V**.

4.1 Action research

In action research, participation and interaction is encouraged. This aids the researcher in studying knowledge in practice and subsequent change in the studied organisation. This also bridges the gap between social science and practice (Reason and Bradbury, 2006), and the usefulness of this approach to deal with environmental issues has been noted as well (Wittmayer et al., 2014; Bradbury, 2001). Knowledge in practice can be identified as a kind of skill used by the practitioner in everyday work. A practitioner can be broadly

defined as a professional working in a specific area. Such knowledge of practice is gained by experience or long-term interaction with other practitioners through dialogue (Wigblad and Jonsson, 2008, p. 313). Donald Schön recognised the importance of the reflections from the practitioners during and after their actions and the opportunity for researchers to study this:

> *Researchers and practitioners enter into modes of collaboration very different from the forms of exchange envisaged under the model of applied science. The practitioner does not function here as a mere user of the researcher's product. He reveals to the reflective researcher the ways of thinking that he brings to his practice, and draws on reflective research as an aid to his own reflection-in-action* (Schön, 1991, p. 323)

The practitioner has knowledge about his/her practice that the action researcher seeks to identify. In the context of this thesis, practice is related to the work done in environmental science in projects and collaborations. When studying and providing incentives for change, it is important to involve organisational members who can then learn and develop together with the researcher.

Action research does not separate theory and practice in the same way as other traditions. In action research, action and meaning cannot be reduced to regularities (Argyris et al., 1985). Involving and evolving the studied community can ideally be done through learning and open critical reflection. As such, intervention is an important part of action research, meaning that participation and interaction are not only possible but also an important part of the scientific process. Action research recognizes that the non-researchers have "*detailed, complex, and valuable knowledge about their lives, environments and goals*" (Greenwood and Levin, 2007, p. 103). This means that participants are active and use action as a way to manage their everyday working life.

One unique criterion for action research is outcome validity. This means that when assessing validity, it is necessary to consider whether or not the studied problem is solved and what the outcome is. Another criterion involves the degree to which the research is done collaboratively and creates awareness among the participants (Herr and Anderson, 2005). The engagement with the participants, make the results plausible for the intended audience as well (Van de Ven, 2007). As such, validity is tested in connection with the participants instead of limiting this to a closed academic community. This occurred throughout this research using various means. Dialogue arenas were used, in addition to other more informal meetings, to discuss the results with the participants.

4.1.1 A pragmatic action research tradition

Two different approaches to action research are the pragmatic and the critical traditions. The critical tradition in action research had an inherited critique of society and a utopian goal of change. What can be called a pragmatic turn in action research, with Jürgen Habermas as a key scholar, resulted in an increased focus on the dialogue between researchers and participants. The idea that knowledge is not exclusive to science but rather a collaborative effort is shared by most action researchers (Nielsen and Nielsen, 2006). The pragmatic tradition increased the emphasis on collaboration, and put less emphasis on the emancipatory change that the critical tradition aims for.

This thesis follows in the pragmatic tradition, with its focus on practical knowledge and cooperation through dialogue. Uncovering and taking part of the participants' experiences and opinions can help tackle issues that occur within the collaboration. Reaching an understanding that can influence the social environment can be done through action and cooperation (Johansson and Lindhult, 2008). Another key idea is never to separate thought from action while maintaining a strong belief in democratic values (Greenwood and Levin, 2007). The way to achieve more knowledge is through inquiry by dialogue and observing the concrete actions of participants.

Throughout this research, democratic values were not defined by emancipation but rather through the inclusion of participants and sectors seeking input from a wide array of participants and sectors in the knowledge production. The collaborative environments in **Papers I-III** were built on such inclusion of participants and the project results relied on the input of the participants.

4.1.2 Abductive approach

When simplifying reality, there is a risk of missing underlying structures and mechanisms. The action research perspective provides an important starting point in recognising the relevance of experiences and practice-based knowledge. From this point of departure, the researcher can collect information and analyse it to reach deeper knowledge. As such action research starts from practice, asking what is happening in the world (Sayer, 1992). What reasoning then, can help explain what and why a certain phenomenon is happening?

Abduction is a form of abstraction where the researcher tries different theoretical interpretations that can lead to new insights. Abduction aims to find the most reasonable explanation for a phenomenon. To be able to do this, practice is reconceptualised through a framework of understanding to show new meanings for an already known phenomenon. The aim is to use theoretical concepts to describe the broader context of empirical observations. This framework can be built upon a model, theory, knowledge overview, norm system or method. This is done by describing empirical observations with the

use of this framework to find patterns. Such a framework can, for example, be the triple helix model:

> *There is no theory about triple helix, but the concept can help us build a theory about something interesting concerning the phenomenon of dynamic innovation within society. The concept can structure the empirical material, useful when deciding which analytical tool to use* (Jensen and Trägårdh, 2004, p. 517)

Starting from a model like the triple helix means accepting certain conditions that are set on a policy or research-funding agency level. Such a starting point disregards how the participants interpret such a model in practice. In **Paper I and II**, triple helix was used as such a framework and in **Paper III** it was the circular economy. The idea was to make participants think and reflect on cross-sector collaboration by using these frameworks. However, throughout the research process, this framework changed in a back-and-forth interplay.

The abductive process moves not only between a theoretical framework and empirical observations but also to practice. An example of this occurred when the participants were confronted with the triple helix framework, and it was shown that their perceptions did not fit the original model. Such an interaction between the research system and the practice system forms the basis for common understanding of the target of the research (Ellström, 2008). The back-and-forth interplay between the framework of understanding and the empirical findings gives input on the theoretical framework from the participants. In this way, the framework changes during the process.

After the research has been conceptualised it becomes possible to define the explanatory part of the methodology. Conceptualising a phenomenon in a new way can make relations visible and provide the foundation for changing and reflecting upon these (Svensson et al., 2002). The abductive thinking was used in the research to find different themes in the collected materials, sorting these and then returning to the field to discuss findings with participants. This movement between the field and the framework was most evident in the dialogue arenas. Dialogue arenas are a method that makes participation and interaction not only possible but also necessary is essential for interactive research, as we will see in the next chapter.

4.2 Interactive research

Interactive research is a type of action research strategy. It emerged as a Scandinavian version of action research used in workplace learning. Interactive research, with its focus on mutual learning, recognises several limitations with action research (Svensson et al., 2007). To begin with, the action researcher has a strong role in organisational change and might become

too involved because of this. There is also a risk that such research achieves only a local understanding rather than a general analysis. Also, action research is a time-consuming process that often limits itself to practical, rather than theoretical, results.

Interactive research aims to solve some of these mentioned issues. The goal for the interactive researcher is to achieve a role that is more or less equal to that of other people in the studied organisation or collaboration. The researcher should be active but not controlling, balancing the distance and closeness to the studied process (Svensson, 2008). There is also need to keep a distance between the research and practice systems and not to become a captive of the latter (Sandberg and Wallo, 2013). This balancing act is necessary when the aim is to achieve understanding from the participants' point of view while still being able to take a step back and reflect upon the research process. As such, interactive research does not emphasise change to the degree that action research does.

When the interactive researcher carries out research *with* the participants, he/she still aims to keep one leg in academia. This is a form of co-development of practice and theory. Additionally, the responsibility of the researcher for change is less in interactive research. All participants can be part of a joint learning process bringing both practical and theoretical knowledge to the research (Johannisson et al., 2008). This allows for the participants to have input on the research process. Throughout the research process, the participants were able to learn from the preliminary research results and the input from participants also validated the results.

Interactive research can even be seen as typical of Mode 3, driven by a democratisation of research where goals will be beneficial to all partners. This would then lead to new knowledge in a dialogue between academics and practitioners. Thus, interactive research is well suited for the work presented in this thesis, acting as a guide for collaboration between university and other parts of society. This mutual learning started from an understanding of what assumptions, duties, and capabilities the participants had. By using the interactive approach, it was possible to stay within the studied context.

Finally, the distinction between interactive and action research and whether or not such a distinction serves a purpose is still up to debate (Nielsen and Svensson, 2006). As mentioned there are significant similarities between the two approaches, especially regarding the engagement with the participants. Both methodological traditions have developed as a reaction to traditional research not being as useful for practice-related problems. There is a theory-practice gap in action research knowledge production. To close this gap, the increased interaction between researchers and practitioners is encouraged, using participatory research methods (Van de Ven, 2007). This thesis is based on such engagement between participants and the researcher, focusing on the processes and results that emerge from this.

4.2.1 Role of the researcher and ethical considerations

Throughout the research process, it was necessary to assess the role of the researcher critically. This meant reflecting on one's role in writing and discussions throughout the process. Combining the researcher role with the role of a project participant in **Papers I-III** sometimes led to dilemmas. For example, the information that was gathered during the process could be sensitive to the project process or the participants themselves. Here theory was used as one way to create a distance from the studied process (Coghlan, 2003; Johansson, 2008a).

During the research process, there was a movement between different researcher roles. Observing a meeting puts different demands on the researcher compared with leading a seminar or planning a project, for example (Rosell, 2013; Mattsson, 2004). This shift occurred several times during the research process. When preparing seminars and meetings between sectors, it was necessary to take the initiative and to become more of a facilitator. During some meetings, however, it was better to keep a passive role while taking notes and observing, and sometimes commenting on the process.

Forester calls for a transformative theory of social learning recognising how dialogue also changes the participants themselves (Forester, 1999). Participatory rituals are an important part of this where participants meet and learn to know each other, for example during breaks and meals in between formal meetings. Normal formal meetings might be too predictable and structured to be able to learn from. During the research, such informal meetings and dialogues often resulted in interesting insights.

During the research processes in **Papers I-III** the role of the researcher varied from being a participant in the project to being a participant in the research group, or both at the same time. This necessitated an extra attention to some issues. One issue was the duality between the organizational and researcher role. Experiences from insider research confirm the advantage of having a deeper understanding of the organization and its resources (Roth et al., 2007; Adler et al., 2004). At the same time, challenges in dealing with multiple roles, a pre-understanding of the studied organisation can become troublesome, if preconceptions about the organisation influence the research.

Being part of the organization was helpful as it provided access to research opportunities. This was true for the conducted research which would not have been possible without the membership in the research group and the projects. At the same time, there were also ethical considerations concerning anonymity when doing this. When involving participants in the research process, the subsequent dialogue can have consequences for the organisation (Coghlan and Brannick, 2014). During the research for **Paper II**, for example, discussions were often centred on what worked well or did not work well, in the project. Participants wanted to be reassured that their "gossiping" would not put them

in any bad situation. In doing so, they trusted the researcher. In turn, it was important to inform these participants about their anonymity.

It was the closeness to participants that made anonymity difficult. Some things that were said might have been relevant for the research; however, the situation in which they were said could have been an everyday informal conversation. Here, it was important for the participants to be anonymous in the research, and that they had a chance to see the resulting text. It was also important to clarify the role of the researcher and the connection to the studied process.

Two categories of participants were identified during the process. The *first category of participants* was those that the researcher had many interactions with during the process. These worked in the research group or were part of the projects. Here, collaboration became natural, but issues of closeness became a problem. It was also here in the research system that the differences between social science and natural science became evident. Most of these had a background in natural sciences rather than social sciences. While this sometimes created friction, there was also a sense of curiosity and appreciation for this research that concerned itself with common questions. This opened up opportunities for discussion about the collaboration that otherwise would not have emerged. A coffee break, for example, sometimes became a significant opportunity for input on some issue or a way for participants to express themselves. As discussed in **Paper IV**, crossing this interdisciplinary boundary was a journey in itself and uniquely so for each research process. Being a social scientist in such a context could be confusing but also helped build up a close relation to the environmental science discipline.

The *second category of participants* was those from outside the collaborations and projects. These were participants in workshops, seminars, study visits and other forms of meetings. These came from different sectors and were involved only to a small extent in the collaboration or project. It was easier to create a distance from these but harder to gain closeness and trust. This interaction mostly occurred in the practice system and can be called the cross-sector boundary. Too much responsibility for developing the cross-sector collaborations would have made the researcher solely accountable for the progress. This also would have taken up time that could have been focused on research instead. One solution was once again to switch between roles. During some meetings the researcher provided support and in other meetings the researcher sat in the audience. Often this was not a problem, and ethical guidelines for qualitative research were used, which meant that participants were informed and anonymised.

5 Methods, materials, and analyses

As the methodological roots are set, it is now time to turn to the methods, materials and analyses. Naturally, these varied and all methods were not used in all papers due to the ad hoc decisions and adjustments that each research process brings. The five different methods, materials, and analyses are discussed in the sections below in that order.

5.1 Methods

In the three qualitative cases, **Paper I-III**, the access to the field was gained through the use of networks and the participation of the researcher in the studied collaborations and projects. Being a part of the research group and being able to use the network of the research group, made it easier to access the field. For **Paper V** access to the research field was not an issue as the survey was aimed at environmental scientists on a national level.

5.1.1 Dialogue arenas

Dialogue arenas were used as a collective term for the seminars, workshops and other meetings places that occurred during the research processes. These were in most cases created by the researcher and had different aims and topics. Such arenas, forums or meeting places have often been used in action and interactive research to create communicative spaces (Wicks and Reason, 2009) where researchers and practitioners can meet. Similarly, dialogue conferences have been used to emphasise the focus on democratic dialogue, participation, mutual discussion, equality and openness (Shotter and Gustavsen, 1999). The disadvantage of dialogue conferences is the long time span, going on for days rather than hours.

Dialogue arenas can be a powerful tool for development and organisational change through the creation of an open forum for communication. One important part is how change emerge from the participants themselves rather than being forced upon them (Ekman Philips and Huzzard, 2007). The idea of co-operative inquiry (Heron, 1996) emphasises that such research be

performed *with* rather than on people. Participants are in this way also co-researchers throughout the process. During the dialogue arenas, the collaborative process was the focus, and research results were discussed with the participants. It was also an opportunity for people that don't know each other to talk freely and come with suggestions to each other:

> *As deliberately diversified small groups meet to discuss problems and opportunities, participants can learn in surprising ways* (Forester, 1999, p. 145)

The interactive research model shown in Figure 6 puts dialogue arenas into the centre of the model. The model was developed in **Paper IV** and is loosely based on a model by Ellström (Ellström, 2008) which emphasises the interlocking of the research and practice systems. The research system contains the scientists and their research related problems. The practice system contains the practitioners with the participants and their problems in practice. Dialogue arenas serve as the hub for this interaction and movement, as illustrated in Figure 6. Ideally, these arenas create knowledge that contributes to both research and practice.

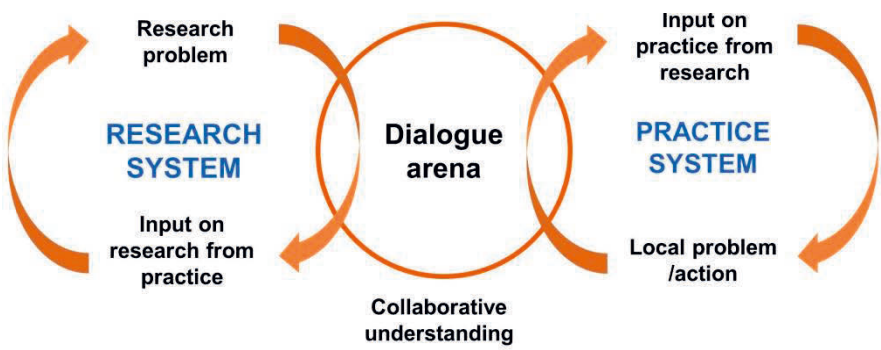

*Figure 6. The interactive research model (**Paper IV**)*

During the dialogue arenas, researchers and participants met, which made it possible for the researcher to get input on the research questions by interacting with the participants. At the same time, the participants also got input on their organisational problems. This was the main way mutual learning was conducted during the interactive research, shown in Figure 6 as a collaborative understanding. These dialogue arenas were constructed in different ways and the researcher had different roles during these.

The dialogue arena conducted for **Paper I** was the only arena not created by the researcher. This was led by an external workshop consultant with the aim to discuss the triple helix idea. It lasted for two days and included 13 of the participants in the project. The goal was to create an innovative space

where the participants could brainstorm and come up with new ideas for innovations and solutions related to the purpose of the project.

During the research conducted for **Paper II**, two seminar type dialogue arenas were carried out with the goal of discussing findings and questions that arose during the research process. In the first seminar, there were four researchers from the research group and one outside the research group. Here, six different themes were presented to the participants. The second seminar included 14 participants from the university sector, company sector, and public sector. This was arranged by inviting previous interviewees and individuals that that took part in the project process by other means. A short presentation of the research was followed by an open discussion about the early findings.

During the case presented in **Paper III**, four meetings were conducted with a total of about 80 participants. These lasted for about 1,5h each. Two of these included a workshop type dialogue arena, led by the researcher. These workshops aimed to get the participants to discuss the waste management and the circular economy. The project team invited participants mainly from companies, industries, and municipalities but others also participated from all different sectors. The discussed themes were based on the project aims of creating incentives for a circular economy using waste management.

These dialogue arenas became a means to open up discussions where participants from different sectors were directly engaged with each other. In this process, new results surfaced, and old results were validated or discarded in a joint effort. In addition to the arenas, results were also discussed with other participants through informal discussions and input on parts of the written articles and texts.

5.1.2 Interviews

Interviewees were selected from both project members and participants in the dialogue arenas. In **Paper I**, it was project members that were interviewed. In **Paper II** interviewees were selected on a qualitative basis, including key individuals from the triple helix sectors encountered during the research process. This was conducted as a form of expert sampling combined with a snowball sampling. For **Paper III** the selection of interviewees was made from two of the workshop type dialogue arenas. These were decided upon together with the project team, and the aim was to represent the diversity of organisations that were present during the workshops.

Interviewing in a pragmatic tradition meant that knowledge gained from interviews represented the participants means of coping with the world (Brinkmann and Kvale, 2015). Each interview guide had themes based on the research problem/questions and theory. The interviews were performed in a semi-structured manner. The interview guides for **Paper I-III** are included in **Appendix A**. Important was also the "*art of second questions*" (Brinkmann and Kvale, 2015, p. 164). This means that it was crucial, during the interviews,

to be active and pick up on interesting points that require further investigation. It was also important to pick up stories that the participants shared during their interviews to highlight or explain a certain point. Letting the interviewee loose and thoroughly talk about a certain subject often led to a good interview situation and material.

Before and after the interview the interviewee was reminded that he/she would remain anonymous. The goal was to create a comfortable interview situation for both the researcher and the interviewee. Before and afterwards it was also important to allow for more informal conversation, introducing oneself to the interviewee and talking about the context of the research. Interviews were recorded using a portable recorder, through Skype and/or directly in a notebook. Transcription was done using a word processor and aimed to capture the full conversation but not including background noise and the physical context.

5.1.3 Documents

Several types of documents were generated throughout the project processes. These were useful both to reconstruct the project process as a narrative and as empirical materials used in the analysis. Most documents that were produced during a project had a potential to be relevant as empirical material. However, excluding irrelevant documents was part of the sampling process, which aimed to include the most important and relevant ones. These documents consisted of protocols from meetings, reports produced during the projects, research applications, publications, PowerPoint slides, memos and even emails.

The logbook was one type of document that helped structure the project process. The frequency and length of logbook entries varied depending on the case and time. There were many impressions and a vast amount of information; thus it was beneficial to write a logbook in the research process (Herr and Anderson, 2005). This was used as a way to keep track of the research process. Sometimes this meant writing a few lines per week in the logbook and at other times half a page in one day to describe an interesting event or thought. By writing a logbook, it was possible to include situations not recorded by other methods.

5.1.4 Observations

Observation methods during this research were performed in a more interactive manner. It was part of the way in which the interactive researcher integrated into the studied community. In doing so it was important to ask questions, observe the context, and not as traditional observation methods, strive to be an outsider (Angrosino and Rosenberg, 2011). There were many opportunities for observation during the interactive research processes. Being part of meetings and study visits sometimes meant a more passive researcher role which gave the opportunity to take in the surroundings and describe the situation. In practice, these descriptions ranged from a couple of rows to about

half a page. Most of these notes were written in the logbook, or on paper then inserted into the logbook. As interactive research was performed continuously, opportunities for observation were sporadic.

A typical observation was performed in the following manner: The researcher took part of a meeting where the project process was discussed, took notes during this time and also took part of the discussions to some degree. These notes included a description of the physical environment, the participants and what role each person had. Furthermore, these notes were entered into the logbook together with a reflection about what had happened and what consequences this had for the project process. This kind of observation was also performed in connection to the dialogue arenas and sometimes photos were taken as well, aiding the description. It was important to catch the whole context of the dialogue arenas, not just the discussion itself.

5.1.5 Surveys

Surveys were an important addition to the interactive methodology. These made it possible to address questions that arose from interactive research process that could not be answered by qualitative research. It is important to use the methods most suitable to answer the research question and in a pragmatic approach the use of mixed methods is important (Feilzer, 2010). The pragmatic approach show a way past a qualitative/quantitative divide as these are equally important to provide knowledge about reality.

An online survey was conducted for **Paper I** to assess the participants' view of the project and the process, with a focus on the interaction between triple helix sectors and the process of international collaboration (see **Appendix A** for full questionnaire). 14 respondents from the project answered the questionnaire.

The main method for **Paper V** was a survey aimed at environmental scientists working at Swedish universities. A database of 1037 emails was created from websites of research groups and research centres, and by contacting research leaders. By using this database, it was possible to send out a questionnaire to these. The questionnaire was available online using the Survey & Report online tool to which each respondent got a link. Before this, a pilot study was conducted within the research group at Linnaeus University. Because of this Linnaeus University was excluded from the study.

307 respondents from 18 universities answered this questionnaire after two reminders. This meant a response rate of 29%. One identified issue was that some emails and websites were not up to date. It was not possible however to determine the number of email addresses that were obsolete or unused. The questionnaire consisted of parts A-G. The questionnaire included background questions, hypothesis-testing Likert scale questions and ending up with open questions. Previous research about collaboration, dissemination, and reflection upon science and research was used to construct the questionnaire. **Appendix**

B contains the full questionnaire and additional information about the respondents.

5.2 Materials

An overview of the methods and materials are presented in Table 7 below. The logbook totaled about 35 pages when including all project processes. An estimation of the total number of documents is about 60.

Table 7. Overview of methods and materials for each paper

	PAPER I	PAPER II	PAPER III	PAPER IV	PAPER V
Dialogue arenas	✓ (1)	✓ (2)	✓ (2)	✓	-
Interviews	✓ (5)	✓ (7)	✓ (15)	-	-
Documents	✓	✓	✓	-	-
Observ-ations	✓	✓	✓	-	-
Surveys	✓(14 respond-ents)	-	-	-	✓ (307 respond-ents)

Qualitative materials for **Papers II-III** were sorted into project cases in QDA miner (Provalis Research) software for qualitative data analysis. The database for **Paper II** included 27 unique files, and for **Paper III** there were 42 unique files. These cases formed databases that made it possible to include many different forms of text materials. The case for **Paper I** was an exception as it was coded in a word editor. A list of the interviewees is included in **Appendix A**. For the quantitative data, SPSS databases (.sav and .xls) were used in both papers. For **Paper V** the database was also imported to R.

5.3 Analyses

In the analysis, the sum was larger than its parts. The different methods together gave clues towards the final results. Using a multitude of methods also required extra attention when analysing these as a whole. While each type of empirical material had its analytical requirements, it was also important to see the whole picture. This meant cross-checking different themes between the types of material to gain an overview and insight into the entire research process. This was a way to triangulate the results with the help of the

abductive process. The exception here was **Paper V** which used only the survey method and quantitative analysis.

In quantitative research, data collection precedes analysis. In qualitative research, there is rather a zig zag movement between data collection and analysis. The analysis of a smaller part of data could benefit the next step in the data collection and so forth. It was necessary to think on your feet and draw conclusions during the process both in thought and in writing. In interactive research, the early analysis was also done in the dialogue between researcher and participants where new knowledge was produced. The analyses of each of the material types are presented below.

5.3.1 Dialogue arenas

The two dialogue arenas in **Paper II** were recorded and transcribed. The dialogue arenas in **Papers I and III** were recorded by taking notes, and the results were discussed afterward. In written form the dialogue arenas were analysed in conjunction with the other qualitative materials. The interactive research model (Figure 6) is an illustration of how the dialogue arenas involved the participants. Here the researcher presented an early analysis to the participants. This gave input to the practice system and at the same time the researcher gained input in the research system.

The dialogue arenas had an additional role for the analysis as well as it involved participants in the process of validating the results. As the interactive researcher presented early data or let the participants discuss around certain topics, this was a form of collaborative analysis. This was necessary for interactive research which aimed to include participants in the analysis as well. This was especially important for **Paper I-III** where the dialogue arenas contributed to the coproduction of knowledge and analysis.

5.3.2 Interviews

Analysis of interviews occurred after transcription. At this stage, the material could be imported into a word processor (**Paper I**) and to QDA Miner (**Papers II-III**). This program helped with coding as well as providing an overview of the material as all types of data could be imported here. Coding was done by attaching keywords based on the interest of the research questions and by further refining these.

When coding it was also possible to identify a "core category" (Corbin and Strauss, 2008, p. 104) which represented the main theme of the research. In the studied cases, these core categories included collaboration in general and triple helix and the environmental issue at hand in particular. It was also necessary to do a theoretical or paradigmatic reading of the interviews. This meant that, by using a chosen perspective, interviews were read through several times. By doing this, specific themes and interests were highlighted (Brinkmann and Kvale, 2015). This was performed in the early part of the

analysis of the interview material before discussing these early results with the participants.

The process of coding began with lower level concepts, more related to open coding, then moving to higher level concepts of categories and themes (Corbin and Strauss, 2008). Open coding was done by reading the whole material, sorting the text into fragments, sorting out irrelevant fragments, assigning and naming the codes to the fragments and re-read the material with the codes in mind (Boeije, 2010). The coding process was influenced by theoretical concepts and ideas formed earlier in the research process. The research problems/questions guided the coding in the same way these guided the creation of the interview guides. While theory influenced the coding process, the goal was not to limit the analysis to any theories.

5.3.3 Documents

Documents are produced for a specific purpose and may or may not represent the actual project process. For example, documents can be fine-tuned many times by the creator to provide an orderly product, or even to make the project process seem better. Even so, reports and minutes were helpful to give insight into the context, supplement research data and strengthen the evidence. Analysis of these was done both by skimming through the documents to get the full picture (Bowen, 2009) and by coding these documents with the rest of the materials.

Analysis of documents was also conducted when these were created. For example, when the researcher produce memos or notes throughout the data collection and during the coding as well (Corbin and Strauss, 2008). These memos and notes contribute to the understanding of the research process and even helped in creating categories for the analysis.

5.3.4 Observations

Observation method served an important purpose in catching the overall overview of a situation. These gave a "rounded up view" of the lives and people within a certain community or context (Angrosino and Rosenberg, 2011). This aided the analysis by describing the context for the rest of the material. These observations were also necessary to complement the description of the dialogue arenas and the analysis of these. As most observations were written in or added to the logbook, these were analysed and coded with the rest of the materials. Using a logbook helped the process of reflection and allowed the researcher to explore new thoughts and insights throughout the research process.

5.3.5 Surveys

For **Paper I** the small population of 14 respondents, from the project team, was expected. As such, only descriptive statistics could be derived from the

results. Statistical software SPSS was used to provide the frequencies and percentages. This survey added to the qualitative materials and the end-results included both of these.

An extensive quantitative analysis was conducted for the data in **Paper V**. Statistical software SPSS and R were used for this purpose. The main statistical methods included: bivariate correlation, path modelling, textual analysis and ordinal regression. Descriptive and frequency statistics were used as well. **Appendix B** includes the supplementary materials where further details about the study and the full questionnaire are shown.

The process of analysis began with *descriptive* statistics to get an overview of the data and running correlations on appropriate variables. Using the means of the different variables, it was possible to get more insight into the data. Bivariate correlations using Spearman Rho (two-tailed) were also performed using SPSS. Reflection and choice of research were the main variables of interest.

Ordinal least squares (OLS) *regression analysis* was conducted using the dependent background variables, in part A of the questionnaire, to predict the ordinal dependent variables. This was done using SPSS and all ordinal variables were tested with all different combinations of possible independent variables. Reflection, choice, and dissemination were the most interesting to explore further, following the hypotheses of the study.

Another technique was the *partial least square path modelling* (PLSM) using R (Sanchez, 2013; Esposito Vinzi and Russolillo, 2013). This made it possible to create latent variables that could be derived from several of the variables. By using latent variables, it was possible to test different models, drawing up paths between them, showing the significance of the path coefficients. Each model formed networks of cause and effect relations. These relations ended up with a terminal node which was the phenomenon that the model aimed to explain. The research ended up with two models that aimed to predict scientist's choice of research and dissemination activities. Additionally, the goodness of fit of these models could also be derived.

Lastly, a *textual analysis* was performed using 93 answers from the first open question, namely: "Do you have any general comments on how science is conducted and what role scientific research has in society?". The respondents were split into applied and basic scientists (about half for each category) using a component based on seven variables (see **Appendix B**). Frequencies were shown, and further analysis was made using a non-linear iterative partial least square (NIPALS) algorithm (Wold, 1975). This method aimed to demonstrate the correlation between the most frequent terms and the strength of these correlations. Finally, a VOS mapping technique was used to map and cluster the use of words in these textual answers. VOSviewer software 1.6.3 was used to perform this analysis. The results from **Paper V** in section 6.5 further show the use of these methods in relation to the resulting models.

6 Results

In this chapter, the results from each of the five papers are presented. All papers are related to theories of knowledge production in different ways and to different extents. Cross-sector interactions were the main focus although this was also present in more general terms as an interaction between science and society. This was studied using the interactive research approach and using the theory of boundaries. Theories of knowledge production also state that the relevance of research has become an important factor. A quantitative approach aimed to answer how environmental scientist reflects upon this and to pave a way forward for future research.

6.1 Triple helix on a management and analytical level (Paper I)

The study presented in **Paper I** was based on research performed during a three-year cross-national project. The goal of this project, with participants from five different countries and three triple helix networks, was to strengthen wastewater research and technology. The idea was for the triple helix partnerships to increase the cluster performances in Sweden, Finland, and Greece by examining the case of olive mill wastewater in Greece. The triple helix model served as the basis for the project, and the participation of three different triple helix partnerships was a unique characteristic of the project. Each sector had a different motivation for participating in this setup: the private sector wanted to extend their networks and earn money, university sector wanted to find technical solutions, and public sector saw it as a learning experience.

Participants were encouraged to reflect continuously on the role that the triple helix played during the project. Throughout the project, an *analytical level* of the triple helix coexisted with a *management level*. This was particularly apparent during the triple helix workshop in Lancaster, UK. A summary of this workshop is presented in Table 8 where the different challenges are shown on an analytical level, and the solutions to these

challenges are shown on a management level. The analytical level had the characteristics of the original intent of the triple helix model as presented in the literature. It was seen as a positive motor for innovation and regional development. It followed a general narrative, stating that collaboration between the three sectors was the key to success. Part of the project goals was to transfer the Northern Europe style of triple helix collaboration to Greece.

The management level, by contrast, became a way of working in the project, with different sectors discussing progress and trying to solve specific problems. The complexity is increased as three triple helices were participating in a cross-national arena. Challenges during the project were often talked about on an analytical level while solutions were discussed on a management level. This was because the participants themselves operated on the management level and it was there that these challenges could be faced. Table 8 shows this tension between the management and analytical levels.

On the analytical macro level, participants and the project documents referred to ideas of structural change, innovation, regional growth, social change, sustainability, culture, and policy. Such ideas were difficult to reach within the limits of a project and through the capacity of the participants. As such a management level of the triple helix was discussed as ways of working in the project. Solutions that were possible on a project level could be related to the participants ways of working. The mix between these two levels was also confusing for the participants from time to time.

Starting from a triple helix perspective was also limiting in a way, as it excluded the civil sector, at least in the beginning of the project. The performance of the project was also hindered by the transnational set-up with staff changes and the limited time to create trust and collaboration between participants. This necessitated a smoother bottom-up process that did not force a triple helix structure to the project. The people side of the triple helix, or "Peelix" as one participant put it, demands additional attention when using the triple helix as a model for collaboration. That is also why the workshop was appreciated and served as a valuable input for both practice and research. Here participants had the opportunity to talk about the collaboration as they experienced it. A top-down triple helix mould did not fit the participants' everyday work, and they experienced the triple helix differently from the analytical level. When providing incentives and pressure for such a model as the triple helix, policymakers and authorities needed to be aware of the reception of this on a project level.

Furthermore, the results point out the importance of trust and social capital in such networks. Trust and social capital can highlight the importance of the people side of such collaborations, in the way trust develops differently on a regional compared to a cross-national level. A narrow definition of a triple helix can limit the development of trust and the function of such collaborations. As such the inclusion of civil sector participants would rather

benefit from a quadruple helix approach on an analytical level as this would, in turn, have an effect on the management level.

*Table 8. Workshop results (**Paper I**)*

THEME	ANALYTICAL-LEVEL CHALLENGES	MANAGEMENT-LEVEL SOLUTIONS
Innovation/ Technology	• Rethinking technology • Orient research to promote growth • Reaching technical solutions and sustainability • Keeping SMEs interested • Use global reach of research	• Work with small steps • Utilize expertise on innovative technology • Use own expertise • See innovation as a practical concept
Triple Helix	• Adding industry and civil sector to double helix of university-public sectors • Finding common interests • Achieving business opportunities	• Identify sector differences • Spread collaboration and openness • Maintain and share connections and trust • Reach companies and markets • Use a small dynamic network
Culture/ Awareness	• Acknowledging social impact, use citizen science • Influencing behaviour • Promote attitude change • Exploit creativity from crisis	• Step-by-step changes • Acknowledge tourism • Put a value on nature • Dissemination • Ask olive mill owners • Respect cultural differences
Industry	• Finding companies that are interested in research as a source of knowledge	• Business mentoring • Have a transparent collaboration • Assess industry • Find financing
Policy	• Finding a holistic policy solution with new wastewater legislation • Increasing responsibility • Countering a challenging hierarchy	• Influence politicians and government • Share responsibility

This paper documented the complexity that emerges when collaborating across sectors and countries at the same time. Through this process, it was found that the network within regions developed differently from the network between regions. On the regional level, there were more chances to meet and get to know the partners, while the cross-national collaboration developed slower and caught up with this process at the end of the project. When regional trust and collaboration evolved, this created a foundation for international collaboration as well. The project had high expectations and the expected innovations and water treatment solutions never reached the olive oil mills during the project period. Part of these expectations came from EU level and the way the triple helix was imposed upon the project structure. Although several management issues did occur, networks did start to form between countries and sectors towards the end.

6.2 Identifying and overcoming the triple helix boundaries (Paper II)

The second paper was based on a study of a long-standing collaboration with the wood industry that was extended by an EU-financed project. Additional actors were brought into the collaboration to enable additional ways to implement research about industrial wastewater treatment. The research presented in **Paper II** was a study of the interactions between the triple helix sectors on a regional level. The overall aim of this paper was to explore what boundaries exist between triple helix sectors in such collaboration and how these can be crossed.

By using interactive research, it was possible to initiate a dialogue among the participants of the project and other invited sector representatives. This was mainly done through the two seminar type dialogue arenas. In these, the participants were able to have input on the research process. Here participants could reflect upon differences and similarities between sectors and their roles in environmental research collaboration. Through interactions based on the triple helix model, the participants expressed concerns, challenges, and solutions related to the collaboration. When the triple helix was used as a framework and topic of discussion, this created a dialogue among the participants, where they remoulded the idea in their terms.

Three different boundaries were identified between the triple helix sectors. The first was the *information process-oriented boundary* (syntactic boundary). Problems related to this boundary concerned breakdowns in information transfer. When using scientific knowledge in cross-sector collaboration, it is important that other sectors can understand it. Those that collaborated with scientists thought that scientific publications were difficult to comprehend. At the same time, the scientists thought that time were too limited to be able to translate this information for other sectors. There was a call for short technical

reports that could be used in industry. Another recognised skill was the ability to be able to talk and communicate with all sectors in an understandable way. Individual boundary spanners were identified as important translators of scientific knowledge when these were present.

A *cultural boundary* (semantic boundary) was also identified. This was present due to the norms and values that vary between sectors. The sectors have different goals, and these are constantly negotiated during cross-sector collaboration. This also means that the sectors frame the environmental problems differently. The problem was framed both as a research problem and as a practice problem. While scientists have to satisfy industry, these, in turn, have to accept the long time frames of academia. There was a tension here between basic and applied research. Sectors outside university wanted practical results, but at the same time, scientists needed to show that their results contribute to the discipline. Further, the research-funding agency also pressured scientists to establish firms and patents. Solutions to these issues were reached through a negotiation between sectors and also an acceptance of each sector's way of working. Time spent in other sectors, in particular for the PhD candidates, aided in crossing this boundary. At the same time, the PhD candidates sometimes felt they spent too much time in the industry.

Finally, a *political boundary* (pragmatic boundary) was present. This boundary was related to the sector-specific ways of working. This was a form of triple helix problem where sectors are supposed to work together even though each sector wants to gain as much from the collaboration as possible. The public sector looks to what is best for the society and has a legislative power advantage. Companies/industries consider the importance of time and money to a higher degree and want to see practical and economic results. The university, by contrast, has a long-term perspective and focus on research that can be published. This boundary was crossed by collaborative work facilitated through informal networks and dialogue. Informal meetings without any prestige were seen as one way to facilitate this collaborative process. Knowing whom to contact was critical and open forums were seen as one way to develop such networks. One solution was to organise dialogue arenas which included the triple helix sectors. The problems and solutions related to the three boundaries are presented in Table 9.

While the sectors saw environmental improvement as a common ambition, the results illustrate challenges and solutions due to three distinct boundaries. These boundaries became visible partly thanks to the new project which increased interactions and partly due to the dialogue arenas. This paper contributes new knowledge about collaborative processes that have been neglected in more analytical, macro level, studies. Collaborations are complex and cannot fully be understood using only models. Informal networks and contacts are essential, and the participants constantly reflected upon their roles.

*Table 9: Problems and solutions related to boundaries (**Paper II**)*

BOUNDARY	PROBLEM	SOLUTION
Information process-oriented	• Academic writing as difficult to understand • Need for someone that can work with knowledge transfer	• Transfer of knowledge using technical reports • Individual gate keepers that can help with knowledge transfer
Cultural	• Sector-specific norms and values • Different ways of working reflected in different perceptions of environmental problems	• Translation through negotiation and adjusting to the other sectors • Spending time in the other sectors where individuals take on boundary-spanning roles
Political	• Sector-specific interests and stakes in collaboration • Triple helix framework as both limiting and enabling	• Informal networks and meeting places • Cross-sector seminars that benefit transformation through dialogue

Entrepreneurship and innovation processes, as well as satisfying the industry with applied results, provided new challenges. For researchers, this meant being confronted with ideas that are not part of the traditional role of the researcher. The tensions between basic and applied research, or in other words a tension between Mode 1 and Mode 2, was shown in the cultural boundary. Further, the political boundary could be related to the sector-specific interests in collaboration emerging from the triple helix idea. On the other hand, the triple helix model was seen by participants as a productive way to collaborate and target environmental problems. A Mode 3 can better describe this due to its emphasis on coexisting ideas for knowledge production. Mode 3 also emphasise the creation of democratic forums for sharing knowledge, conducted in a framework consisting of a common ambition to improve the environmental problem at hand.

6.3 Bridging research and practice using the circular economy (Paper III)

The aim of the collaborative project studied for **Paper III** was to bring the idea of a circular economy to participants outside academia. Workshop type dialogue arenas were facilitated to bring a diversity of participants together. In doing so the project team reached out to a wider audience with their research results, this was a way to bridge research and practice, leading to

environmental improvements. The dialogue arenas served as a way to disseminate knowledge and also get input on the results of the project. Furthermore, the project report, matchmaking and study visits were ways to achieve this. This helped to close the gap between research and practice, as well as between waste management companies and the participants. The circular economy was used as a rationale for the project and used to situate waste management in a wider societal perspective.

As most participants were interested in the practical issues concerning waste management, this was the focus of the dialogue arenas. Waste management worked as a way to bring the idea of the circular economy to practice. The examples from the project team and other invited speakers were appreciated and relatable. Waste management was perceived as concrete and had practical application. During the dialogue arenas and interviews, participants related the circular economy to alternative concepts that had such a concrete and practical use, for example reuse, recycling, second-hand and industrial symbiosis. The circular economy had elastic properties in the way that participants could relate this to other ideas and concepts.

The circular economy rather existed as an abstract macro level idea - *an epistemic object*. The idea was used by different sectors and with a different meaning for each of these. The definition of such an epistemic object depends on the situation, and it stimulates further inquiry and more questions. This was also the case for the circular economy during the project, in particular how this concept got a diverse set of participants together to discuss waste management. As a successful object, this improved collaboration. While the idea of a circular economy was a target, and end-goal to strive towards, waste management was the practical means of moving towards this goal.

As shown in Figure 7, waste management can be the transformative means due to the ability to implement these and create improvements in organisations. The circular economy served as a normative ideal which motivates the transformative means and sets the goal for these. The dialogue arenas and the work conducted by the project team served an important purpose in bridging waste management and the circular economy. In summary, the research showed that the circular economy was useful as an idea that people could strive towards. Even though the idea is unreachable, it served a purpose as an epistemic object to bring participants together and discuss improvements to waste management. It was shown that such an epistemic object could be useful for managing knowledge across boundaries.

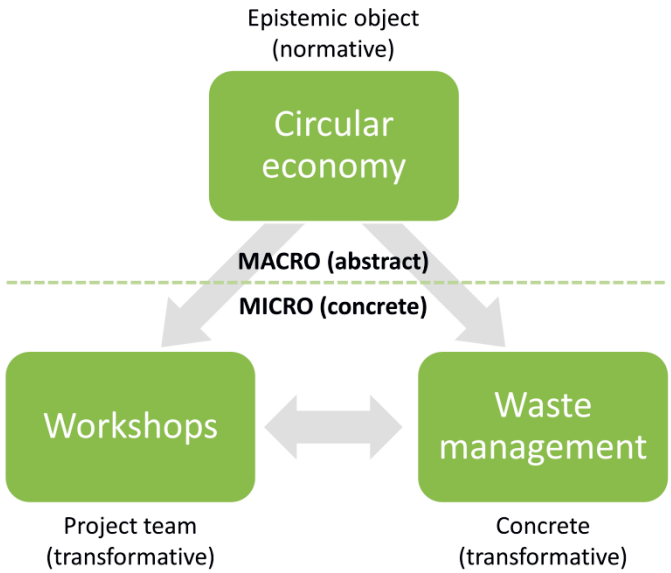

*Figure 7. Facilitating the move from abstract to concrete (**Paper III**)*

Waste management then became the more concrete and practical application of the circular economy idea. As such waste management could aid in the transformation of society towards the normative goals inherent in the circular economy. The circular economy further served a purpose in bridging research and practice, which could be used as an opportunity to discuss environmental improvement.

6.4 Managing boundaries between sectors and disciplines using dialogue arenas (Paper IV)

Paper IV drew mainly from the experiences of **Papers II-III** by presenting the interactive research methodology and in particular the method of dialogue arenas. Further, this paper critically assessed the role for interactive research in cross-sector collaboration. An additional challenge for the conducted research was the fact that it was carried out within environmental science, a natural science discipline.

Dialogue was important to initiate reflection among the participants in collaborative projects, and the social scientist aided such a dialogue. Bringing together different sectors also meant a democratic form of knowledge production, not limited to the university sector. Dialogue arenas made it possible for the researcher to stay within the context and to spark a dialogue among participants. Here it was important to balance the researcher role

between distance and closeness and also manage the balance between the research and practice system (see also Figure 6 in section 5.1.1).

Two forms of dialogue arenas could be distinguished: the seminar type and the workshop type. These had two internal boundaries in common, which the interactive researcher encountered. The first boundary was found in the research system, and it concerns disciplines. The second boundary was found in the practice system, and it concerns sectors.

The challenges that occur due to the *disciplinary boundary* between social and natural sciences, in the research system, surfaced because of several reasons. Results showed firstly that inquiries from social science raised questions and even suspicion among more natural science oriented participants. Interactive research meant a very different method than the natural scientists were used to. Second, even though the social scientific point of view was appreciated, the usefulness of the interactive research needed to be proven. Lastly, there are differences between scientific paradigms, where environmental scientists often frame the environmental problem in technical, positivist terms.

In this context, social science served as a way to disrupt the usual mode of science. This was mainly done using the dialogue arenas, which made room for the interactive researcher to clarify the role of social science. This provided an added value to the usual technical processes and made it possible to facilitate a discussion about collaboration itself. This in turn stimulated a self-reflection among the participating natural scientists.

The *cross-sector boundary* in the practice system brought further challenges for the interactive researcher. Cross-sector collaboration led to challenges when disseminating results and knowledge beyond the university. Dialogue arenas were a boundary-spanning activity that created a forum where participants from a variety of sectors contributed to a discussion about environmental issues and collaboration in general. These included participants from the triple helix sectors, mainly: companies, industries, municipalities, regional authorities, university, but also other participants that were not part of any defined sector. This helped to bridge the gap between research and society.

The participants appreciated the fact that university opened up for such a dialogue. In particular, the participants acknowledged the importance of social scientists to stir up discussion about cross-sector collaboration. Using the triple helix model as a starting point here, from a bottom-up approach, made participants reflect upon their sector and its relation to the other sectors. Moreover, as is the strength of interactive research, research results and the validity of these could be tested with the participants during these dialogue arenas.

Table 10 shows the value of dialogue arenas to manage the research and practice systems. Dialogue arenas served as a key method for solving challenges related to the disciplinary boundary and the cross-sector boundary.

Dialogue arenas created a space where collaboration could occur cross the disciplinary and sector boundaries. By setting up these meeting places the interactive researcher was able to show how social scientific research worked and that it could help practice. In this way, the interactive researcher aided the cross-sector dialogue where theoretical ideas were defined in a bottom-up through a collaborative effort. These dialogue arenas helped the researcher to manage the two boundaries.

*Table 10. Effects from dialogue arenas (**Paper IV**)*

BOUNDARY	BENEFITS OF DIALOGUE ARENA
Natural / Social sciences in the research system	• Clarifies the role of the social scientist and bridge ontological and epistemological differences • Sparks curiosity about and facilitates the collaborative process • Inspires a self-reflection among the scientists and their relation to practice
Cross-sector collaboration in the practice system	• Facilitates a democratic dialogue about collaboration • Making each sector representative reflect upon their role and relation to other sectors • Making sense of theoretical ideas (triple helix, circular economy) in practice • Tests the validity of research with non-researchers

6.5 Environmental scientists and the relevance of research (Paper V)

The main aim for **Paper V** was to find out more about how environmental scientists reflect upon the relevance of their research. This was done by answering three hypotheses:

H1: Most environmental scientists reflect upon the social and environmental relevance of their research
H2: The reflection upon this relevance influences the scientists' choice of research
H3: The degree of dissemination activities depends on the scientist' reflection about social and environmental relevance of their research.

The results of the survey clearly showed that most respondents did reflect upon the impact of their research and answered that their choice of research was affected by its potential impact on society and the environment. This result was further established by the bivariate correlations between the four questions about reflection and choice (see the supplementary material in **Appendix B**). When ranking definitions of usefulness the top-ranked definition was that useful research should provide findings that can "influence policy-makers and industry actors in making decisions that will be beneficial for society". This meant that the respondents did not choose a definition of useful research that was related to advances in disciplinary knowledge. The main results are illustrated in the three figures below. Figure 8 presents a model that explains what variables that have an effect on the scientists' *choice of research*.

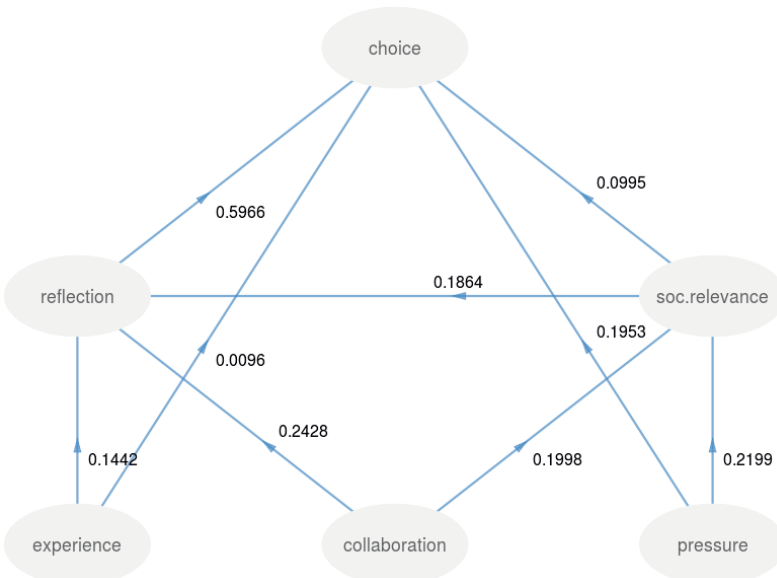

*Figure 8. Overview of the choice of the research model (**Paper V**)*

Each ellipse in Figure 8 is a construct of several variables (further explained in section 5.3.5). Each path is illustrated by a line, that also shows that a higher number is more significant. All paths are significant, at the 5% level, except between experience and choice. The model has a goodness of fit of 0.38 which represents the average R^2 value (coefficient of determination). What this model shows is that choice is influenced by several constructs which in turn are influenced by other constructs. Reflection, in particular, was important to explain the choice of research. With increasing research experience there was also an increase in the reflection. The attitude to collaboration with other parts of society also influenced this reflection and also the attitudes to the societal

relevance of research. These attitudes to societal relevance were influenced by the pressure to produce relevant research, and the attitudes did to some extent influence choice. Pressure had a direct impact on choice.

In other words, the results showed that the reflection influences the choice of research. If the scientists thought that the relevance of research was important to consider, and they had positive attitudes to collaboration with non-academics, this also explained their choice of research. The experience of the scientists increased the reflection, but there were also pressures on scientists to perform relevant research. Increasing interactions with society and larger networks seemed to trigger such a reflection. It is likely that dialogue with actors outside academia contributes to a reflection. On the contrary, a young scientist without many interactions with external collaborators would be likely to have less to reflect upon.

Further, the paper included a model with *dissemination* as a terminal node. This model is shown in Figure 9. The effect on dissemination from the constructs experience, reflection, and collaboration were tested. Results showed that reflection was of less importance here but still had an influence on dissemination. Collaboration and in particular experience were significant, on the 1% level, in explaining dissemination activities as well. The goodness of fit in this model was 0.41.

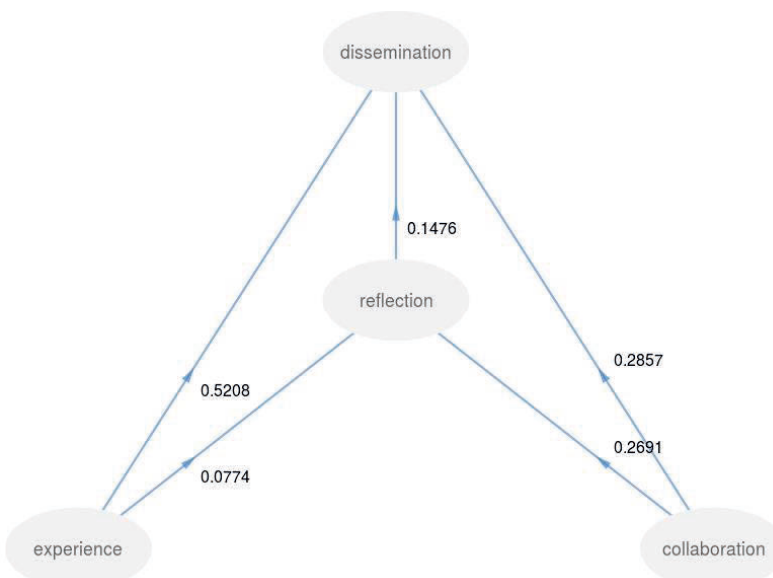

*Figure 9. Overview of the dissemination model (**Paper V**)*

The results from the conducted text analysis is presented in Figure 10 below. It shows differences between applied and basic oriented scientists regarding how they *reflect upon their research*. It shows what terms these two different groups used express this reflection. Applied scientists relate to this with words like funding, publication, money, results and industry. As such, these scientists reflect more upon issues of collaboration. The basic scientists rather emphasise the environment, knowledge, development, future and responsibility. These terms show a reflection that is more related to the value of scientific progress in itself and how this can improve society and nature.

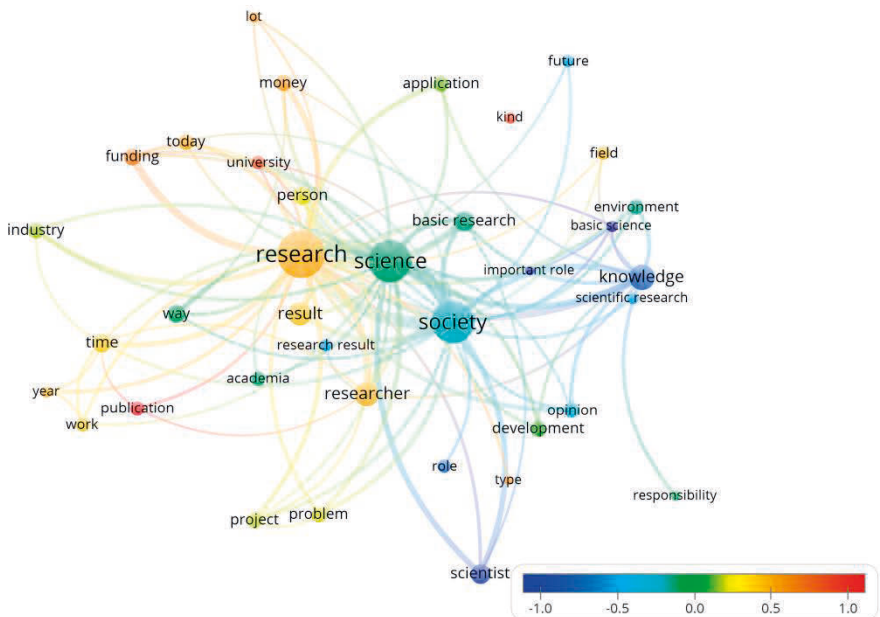

*Figure 10. Term network with nodes coloured proportionally to average orientation of the researcher who used the corresponding term: blue = basic-science oriented, red = applied-science oriented (**Paper V**)*

This study aimed to answer to three hypotheses, and the results supported the claim of all three. Scientists reflect upon the societal relevance of research; this influences their choice of research and their dissemination activities. These results are consistent with the Mode 2 idea that the demands and incentives for relevant research are a part of contemporary knowledge production. This paper shows that this is the case in environmental science. In this study, scientists were shown to acknowledge that research ought to provide relevant results and they felt pressure to provide such relevant results.

The results also provided an opportunity to learn more about how scientists collaborate and to what extent. In doing so, the results contribute to knowledge about how environmental scientists reflect upon the relevance of

research. This expands the horizon to a national level of inquiry, going beyond the three interactive research processes. This study highlights how the scientists perceive the demand from society to produce useful research. The idea of usefulness cannot be separated from the issues discussed in **Papers I-IV,** which provide examples where science and society meets and the idea of relevance is constantly negotiated. The demands from the collaborating partners have real effects on how research is conducted.

7 Conclusions and discussion

Throughout the research, collaboration was a way to approach environmental issues by bridging research and practice. Theories of knowledge production have been used to understand such collaborations. In addition to this, these theories of knowledge production emerged in the practice system as different approaches to collaboration. In this way, the collaborative approaches to solving the environmental issues became influenced by ideas on a macro level. This tension between macro and micro, and research and practice was present throughout the research. The key points of each paper are presented below:

- The triple helix becomes something different on a project level. Rather than forcing a triple helix upon a project, the participant perspective needs to be considered
- When working in an environmental collaboration based on the triple helix, participants encounter political, cultural and information-process oriented boundaries each with its solutions
- When working with a macro level environmental goal such as the circular economy, such an epistemic object can serve as a driver for change that helps to bridge research and practice
- Dialogue arenas serve as a means for the interactive researcher to bridge sectors and disciplines, and for the participants to reflect upon the collaborative process
- Environmental scientists reflect upon the societal relevance of research, which has an effect on their choice of research and dissemination activities

When put together, the papers fill knowledge gaps about the interactions between scientists and society where the relevance of research is constantly defined. Do you remember Latour from the introduction? Rather his statement: "*Have we come all this way and escaped the Charybdis of 'science' only to be wrecked on the Scylla of 'society'?*" This thesis contributes to knowledge about the balance between these two extremes. The focus of this

thesis has been processes where cross-sector partnerships approach environmental problems. Increased interactions and an increased emphasis on the relevance of research for society are two key features in the presented theories of knowledge production (Hessels and van Lente, 2008). This thesis reveals the presence of these two characteristics in environmental science and provides knowledge about these. Further, the thesis clarifies the consequences of these characteristics for practice.

The first section below aims to answer the two research questions in the thesis: How does environmental cross-sector collaboration work in practice and how can interactive research be used to study and facilitate such collaboration? How can theories of knowledge production be used to understand environmental science? After this discussion, limitations and future research, relevance for practice, and a final reflection, sum up the thesis.

7.1 Solving environmental problems through collaboration

Environmental research collaboration requires crossing disciplinary, organizational and national boundaries. Crossing these can lead to an increased complexity and difficulty in managing the collaboration (Perz et al., 2010). Previous research has recognised the importance of interdisciplinary collaboration between social science and natural science to target environmental issues (Bryant, 1998; Pohl, 2005; Holm et al., 2013; Lang et al., 2012). Environmental science can become a meeting ground between social sciences and natural sciences, but such an interdisciplinary approach need to recognise and reconcile the differences between disciplines. On a positive note, this can lead to a fruitful reflection on different research models, concepts, and philosophies of science.

Scholars are often surrounded by peers in their disciplines, which can limit their horizon to established paradigms (MacMynowski, 2007). Collaboration between the macro sciences, such as social sciences and environmental sciences, bring with it challenges due to different paradigms and methods (Evans and Marvin, 2006; Lowe and Phillipson, 2009). During environmental research collaboration, the challenge of collaboration itself is rarely the main concern, neither is it a goal in itself. It is rather the environmental and technical processes that are prioritised over social and organisational issues. However, when environmental problems are defined by technical means, this eliminates important social factors:

> *Technology-based, end-of-the-pipe regulatory standards may not prevent environmental degradation or ensure the protection of ecosystem integrity, but they are generally preferred by the*

> *scientific community over solutions that call for modifications in human behaviour […] When problems are technically defined, decision choices are narrowed to options that can be technically measured rather than those that require open discussion of preferences* (Cortner, 2000, p. 24)

The interaction between science and society also means that society gains ways to influence the research agenda and define the relevance of research. Environmental scientists themselves are aware of this influence. Scientists involvement with society has even been shown to trigger a counter reaction among those that want to keep their disciplinary boundaries (Swan et al., 2010; Waterton, 2005). Environmental scientists, and likely those in most disciplines, reflect upon the current state of science and the trend towards more involvement with and demands from society. In turn, such reflection is likely to impact the interactions between sectors.

Results from **Paper V** showed that ¾ of the responding environmental scientists at Swedish universities answered that they have at some point during their research collaborated with partners outside university. This hints to the extent in which environmental scientists take part in cross-sector collaboration. This is not surprising as solutions to environmental challenges need to consider a diverse set of stakeholders and participants (Hage et al., 2010; Polk, 2015). These challenges require scientists to acknowledge the interests of civil society and the general public. The engaged scholar and the integration between academia and society are recognised as a key for solving environmental issues (Whitmer et al., 2010). These collaborative approaches have become increasingly integrated into knowledge production.

Certain environmental issues span sector and disciplinary boundaries by definition. What has been called "wicked problems" include environmental issues that are hard to define and find solutions for. Wicked problems also have political ramifications and wide stakeholder involvement (Roberts, 2000). Rather than an interdisciplinary approach, the idea of transdisciplinarity has been proposed as a solution in addressing such critical and complex environmental issues. Transdisciplinarity means that the target problem is approached by multiple disciplines and societal sectors working together (Figure 11). Such an approach need to cross both disciplinary and cross-sector boundaries (Hadorn et al., 2008). Collaboration can narrow the distance between research and industrial application. Collaboration can help find solutions that benefit all participating sectors and, in the end, the environment itself.

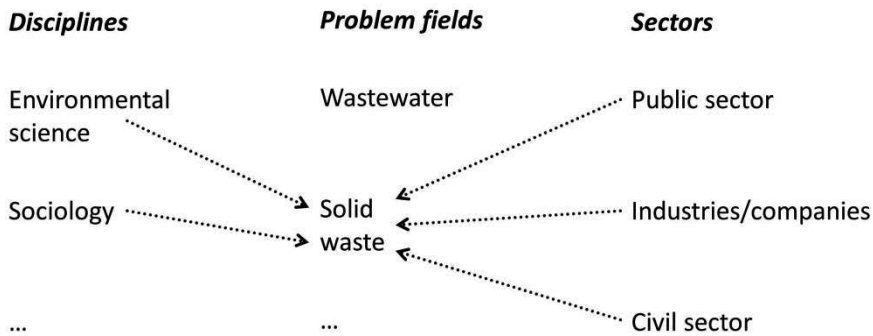

Figure 11. Transdisciplinary approach to problem solving (based on Hadorn et al., 2006)

Transdisciplinarity and collaboration are useful when the issue at hand has uncertain definitions and solutions. Large scale problems which affect "the commons" of the environment often necessitate the inclusion of a variety of participants. Multiple stakeholders from local to global level and different sectors are often included in a dialogue to reach possible strategies. Elinor Ostrom also highlighted the importance of finding such common ground (Dietz et al., 2003; Ostrom, 1990). The natural environment itself was found to serve as a common ground, which makes it possible to approach problems in a collaborative manner. Such collaboration, as this thesis has shown, creates tensions and challenges.

7.1.1 The tension between macro and micro as a collaborative challenge

Throughout the research, cross-sector interactions were present on a micro level. Many of the tensions on the micro level come from macro level theories of knowledge production. For the scientists, it came naturally to consider the relevance of research when working with industry or the public sector. For example, industry might ask "*How will this improve our water treatment capabilities?*" and public authority might wonder "*How can this help us make better decisions about waste management?*". Answering such questions and at the same time keep to one's own research interest can be difficult. This is a challenge that emerges when crossing boundaries.

Paper I showed how the triple helix model was used in a project environment on an analytical and management level. This demonstrated how a macro idea like the triple helix became something else in micro-level collaboration. This research also showed that such an idea could limit the collaboration process if it excludes certain sectors. **Paper II** showed the different ways in which boundaries are encountered and dealt with when collaborating in a triple helix environment. Challenges could be related to three kinds of boundaries which reflected the different ways of working between sectors, norms, values and interests. Results showed that knowledge

needed to be transferred and translated between sectors, which could be done by individuals and through negotiation and adjustments to the other sectors. Dialogue arenas served a purpose in transforming the knowledge and manage the different interests and stakes that each sector has.

A common theme throughout the research was the macro level theories of knowledge production that coexisted with the micro level ideas in practice. This was a two-edged sword, however, considering both the triple helix model and the circular economy. Both of these ideas made interaction desirable and created a bridge between research and society. On the other hand it "locked" the collaborative process to particular frameworks with the expectations that this bring.

Theories of knowledge production are in a sense also normative, especially when incentives to structure collaboration in certain ways emerge from such theories. When these ideas are used on the micro level, they become something different than originally intended. This thesis has shown that theories of knowledge production can create confusion among the participants, but can also bring participants together when these theories are used as a motivation. The participants' reflection on the theories can become increasingly productive through the use of interactive research and dialogue arenas. The advantage of this is the way it focuses different capabilities towards problem solving. Scientists are then confronted with other parts of society and have to show what input their research does to the practice system.

The triple helix model was a starting point for the research in **Paper I-II** where it was used as a framework. The rigidity of this model made it questionable further on in the research process when the actual practice was revealed. In a way, the concept was remoulded, as each participant used it differently. While the original model emerges from an analytical level, it was also used on a management level. In this thesis, the triple helix was a framework to understand interactions between the three sectors. This was also present in the research context.

The circular economy in **Paper III**, although not a theory of knowledge production, is also an idea that is situated on a macro level and used in another manner in practice. Abstract ideas create both confusion and possibilities for collaboration. The collaborative possibilities that emerge from these theories make them useful. At the same time, the confusion and distortion that emerge require additional management efforts from the collaborating participants. Theories of knowledge production and other abstract ideas require a space where these are defined and "unpacked" on the micro level and such a space can bridge research and practice.

7.1.2 Interactive research as a way to manage tensions

The role of the interactive researcher as a facilitator of interactions between science and society is another theme throughout this thesis. Of course one could leave the environmental scientist alone in their endeavour of

collaborating, and they would likely be fine. However, bringing along a social scientist brings both new knowledge and a form of dissension that stimulates new thinking about everyday situations. This brings real challenges but also opportunities for learning. Scholars of science and technology studies can, for example, take such an approach into consideration when studying other disciplines.

The creation of dialogue arenas was a way in which environmental problems and collaborations were discussed with a wider audience. Dialogue arenas aided the interaction between scientists and society by encouraging the engagement between scientists and other participants. This method helped bridge the gap between science and society. This method also provided insight into the participants' practice and this, in turn, gave participants the opportunity to give input on the results.

This thesis suggests that technical and natural scientific inquiries need to be addressed jointly with the challenge of collaboration. Ideally, this can help facilitate both the collaborative process and be a way to reach out to a wider audience thus solidifying the relevance of the research. This creates an arena for participants to stop and think about the collaborative issues. The utility of the interactive research approach relies on the assumption that the gap between research and practice can be overcome. This methodology made it possible to challenge these dichotomies and solve the problems that are related to them. Part of this approach means finding challenges that originate in differences between sectors and disciplines.

When a project is influenced by a collaborative approach to the environmental issue, such as the triple helix model, this has an effect on how the issue is solved. In **Paper IV** the role of dialogue arenas is examined, especially how these were used to manage disciplinary and cross-sector boundaries. Dialogue arenas help to clarify the role of the researcher and create a space where the collaboration itself can be discussed. The arenas help to facilitate the move between micro and macro. When macro ideas are discussed on a micro level, this reduces the confusion surrounding these. Dialogue arenas bridge research and practice, and contribute to a democratic research process. The presence of an interactive researcher in the process can help to make the approach more visible to the participants. Participants might inquire about the collaborative process even without the interactive researcher, but they might lack the tools necessary to study the process.

With the use of dialogue arenas, a new process was initiated, when going from an environmental issue to a solution. A simple linear process might produce the necessary results and solutions. However, the actual collaborative process is more complex than this. The model in Figure 12 presents two views of the collaborative process in connection to this thesis. *Path 1* in the figure is a collaboration that begins with an idea or theory that create the incentives for collaboration. Ideas such as the triple helix model or the circular economy can be highly visible, as shown in this thesis. Following *Path 1* this idea should

result in a collaboration that tries to solve an environmental problem. The original idea on an analytical level might disrupt this process, enhance this process, or even be forgotten. Eventually the collaboration, if successful, ends up with more knowledge about the environmental issue and even solutions to the environmental problem.

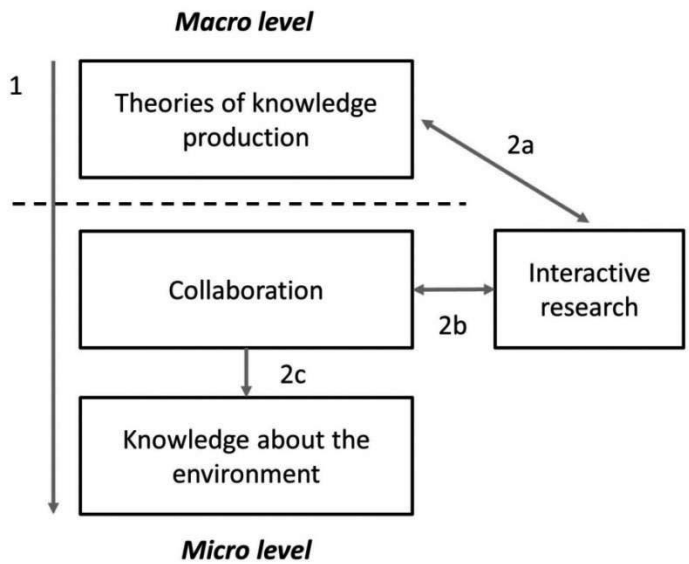

Figure 12. Collaborative processes in environmental research collaborations

This thesis has shown that there are challenges that occur when ignoring the social and organisational issues following *Path 1*. Confusion about the theories of knowledge production can surface, and additional challenges emerge from the crossing of boundaries. As such *Path 2* is a suggested way towards improved performance in collaborations. *Path 2* helps to discover problems related to analytical ideas and collaboration, which can then be solved or at least acknowledged.

As mentioned, the challenge of collaboration itself is not the main concern in *Path 1*; neither is it a goal in itself. Here the environmental and technical processes are prioritised over social and organisational issues. *Path 2* on the other hand was the approach in this thesis, which introduces interactive research which sets in motion a reflection on the collaborative process and the macro level theories of knowledge production. Starting with *Path 2a*, these theories can be analysed and brought down to the practice level. Following *Path 2b*, a dialogue about collaboration itself can be initiated with the participants, which can include the analysed theories from *Path 2a*. This gives input both to the practice and the research system where the interactive researcher resides. Dialogue arenas are one way to reach a collaborative

understanding. When the collaboration itself is discussed, problems and solutions related to this can be resolved. Participants can then proceed down *Path 2c* to coproduce knowledge about the environment. The interactive researcher, in most cases, has less knowledge than the participants about the environmental problem at hand. This means that the role of the interactive researcher in *Path 2c* is downplayed.

7.1.3 A Mode 3 of knowledge production

The presence of different theories of knowledge production and the increased focus on the relevance of research, which emerges from cross-sector collaboration, can be seen as a Mode 3. Mode 3 can be used to understand this as it recognises the diversity of theories about knowledge production. Mode 3 provides a framework that recognises the inclusion of a fourth helix of importance to knowledge production and innovation. This fourth helix is seen in this thesis as the public sphere or society in general. The fourth helix is present as pressure from society, research funding agencies and the reflection upon the relevance of research from the scientists. As such society makes itself known to the scientists even if civil society and other groups are not included as collaborative partners. That is the democratisation of research inherent in the Mode 3 of knowledge production.

In the revised quintuple helix, model illustrated in Figure 13, cross-sector interactions form the foundation for collaboration. As the triple helix model had a real impact on the way in which cross-sector research collaboration was performed, the collaborative perspective should be included in the model. In this way, collaboration on a micro level can be related to the influence that the different helixes have on this. Society is shown in Figure 13 as the way in which societal relevance of research is present in the collaboration. The pressure of providing societally relevant research becomes a challenge when the research is democratised and the interactions between scientists and other participants intensify.

The natural environment, as the fifth helix, becomes the driver and motivator for collaboration. It can frame the environmental problem as an epistemic object. It is the foundation that is always in the background and ideally in the foreground of environmental research collaboration. In doing so the environmental relevance emerges and, similarly to the societal relevance, motivates and drives the collaborating sectors. This environmental relevance provides a common idea and goal that can steer and motivate collaboration to solve environmental problems. **Paper V** showed how the relevance of research was reflected upon among environmental scientists.

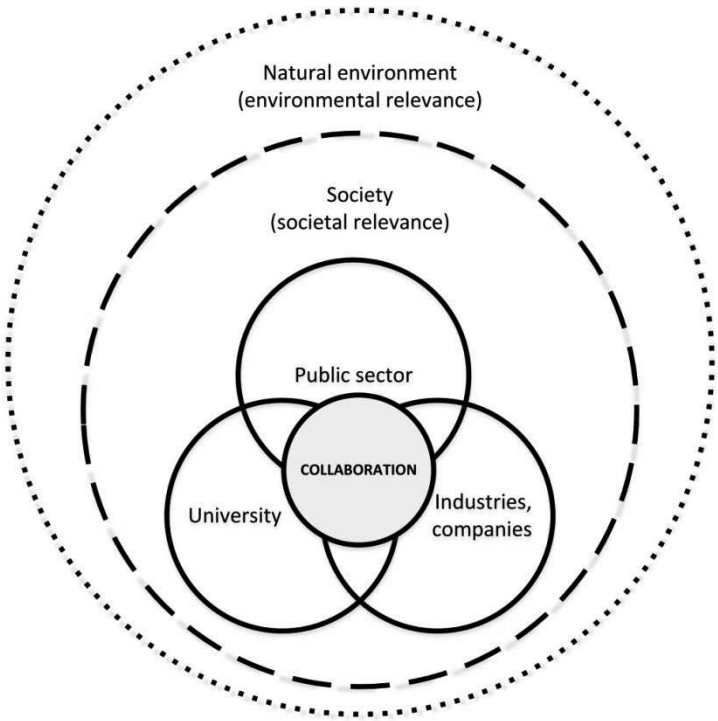

Figure 13. The quintuple helix model (updated from Figure 4)

The idea of a fifth helix that concerns the natural environment means that environment itself creates a framework for collaborative knowledge production. The environment becomes a part of knowledge production as a driver for new ideas and eventually innovation. As such the natural environment serves as a reminder to the knowledge production process, that without it, there would be fewer opportunities for collaboration and innovation. In cross-sector collaboration, there are different perceptions of the environment, but the environmental problem is always present to motivate the collaboration. If the environment itself becomes the main driver for such collaboration, rather than competing theories of knowledge production, this clarifies the goals of the research. The inclusion of the natural environment from the beginning helps to focus the collaboration on the environmental problem at hand.

The circular economy idea in **Paper III** was revealed to be an abstract idea that served as a goal that motivated collaboration and had practical relevance when cross-sector collaboration was initiated using this. The circular economy was a successful idea that emphasises an improved management of our limited resources. As an epistemic object, it served as a way to motivate collaboration towards an environmental end-goal.

What other macro level ideas, more specific than the natural environment itself, can contribute to collaboration and create common goals? There are several contenders. One alternative can be the idea of planetary boundaries. These show the limits of our earth and that we are surpassing several of those limits (Steffen et al., 2015). Another idea is that we live in the Anthropocene, which means that human activities are changing the environment to such a degree that we live in an epoch defined by this (Steffen et al., 2007). Climate change could also be such a macro level driver that can serve as an important framework for collaboration. There are also the 17 UN sustainable development goals that were adopted in 2015. The point is that a quintuple helix model can introduce macro level ideas that are directly driven by their environmental relevance.

Hopefully, the lessons learned from this thesis contribute to environmental research collaborations in particular and research collaborations in general. If research collaboration can be done in a better and more inclusive way that would in the end benefit all collaborative research. However, it might be too bold to say that the results contribute to an improved knowledge production. Rather one should talk about an inclusive knowledge production which can help scientists to deal with the relevance for the environment and society. This would make research more thoroughly situated in the environmental and social context, the advantage of this being a shared responsibility between science and society. This in turn can redefine relevance as a process, a productive way of approaching problems, rather than forced ideas that create negative pressure on scientists.

7.2 Limitations and future research

In the licentiate thesis (Rosenlund, 2015) that preceded this thesis, the question was asked how environmental scientists reflect upon the third mission and the societal and environmental relevance of their research. This has now been approached in **Paper V**, and the results show several new areas, which motivates further research. This study also had its limits as it was solely targeted at environmental scientists at Swedish universities. Including more disciplines and even more countries would be one way to expand upon these questions.

A qualitative approach to this reflection would provide a deeper understanding of how scientists reflect upon these issues. The text-based answers in **Paper V** hint at this. Such an approach could also make use of the developed methods such as the dialogue arenas. It is possible to create a dialogue about societal and environmental relevance by including a broad range of actors, which would likely also help scientists understand and reflect upon this in a dialogue arena. Ideally, such a process can bring a collaborative understanding where the relevance of research emerges democratically. To

also include policy makers in this process would further improve the implementation of analytical level policies, which in many cases are emphasising societal relevance. Another route for further research can be the study of policy and in particular the role of boundary organisations, in such policy processes.

Additional research could also contribute to a theory of the practice of environmental collaboration. The idea is that those that work with environmental problems in collaboration will adopt a specific way of working. This can be a learned skill enabling the work of the participants to run more smoothly and successfully, as Donald Schön has suggested in his book "The Reflective Practitioner" (Schön, 1991). Such skills can include different ways of dealing with the other sectors and balancing this with one's role, and the costs and benefits of such collaborations. Other skills could include the ability to understand and to talk to all different sectors. Many of the appropriate skills are probably not restricted to environmental work. Individual attributes and chemistry between individuals could be another target for future research.

Another interesting study context would be bottom-up quadruple helix interactions where civil society is represented in collaborative projects. Ideas for such a study have already been initiated during the writing of this thesis. The studies in **Paper I-III** were also limited by the interactive research approach. While this approach provides a deeper understanding of long-term collaborative processes, it can only deal with a few cases at a time due to the time-consuming nature of the research process. Comparison between larger numbers of cases of collaboration could bring a deeper understanding of the societal relevance of research and cross-sector interaction.

7.3 Relevance of this research

A thesis that considers the societal relevance of research, the importance of practice and the value of making research available for non-academics, ought to include some considerations of its practical use. The presented methodology has wide applicability. The means to reflect upon collaborative processes can be employed on a smaller scale and for shorter periods. Anyone involved in cross-sector collaboration can stop for a minute and assess the situation, and perhaps arrange a dialogue arena for the purpose of discussing the collaboration itself. The method of dialogue arenas is not unique for interactive research as there are many ways to create room for dialogue.

Collaborations are complex, and the challenge of collaboration has not been fully solved and it might never be. One motivation for the thesis was the countless time's participants stressed the need for research about collaborative processes and means to reach out to this or that sector. In doing so, the participants themselves confirmed some of the challenges that this thesis sought to investigate.

One question to ask at the end of such a study is whether or not change did occur and whether the researcher influenced it. While difficult to measure, it was apparent that the interactive research process had an impact on the participants. Dialogue arenas created new opportunities for meeting and dialogue. Participants referred to this afterward and sometimes brought ideas back to their organisations and even to their private life. The end results of such interventions are difficult to predict. Environmental change is a long-term process, which ought to be recognised by both social and natural scientists.

Furthermore, the actual descriptions of the cases can serve as examples of environmental cross-sector research collaboration, which can be role models for similar projects. The unpredictability of the results from such collaborations is one lesson. It is also relevant to highlight the importance of the individual factors. In the end, it is people who need to work together, bridging the different ways of working. One suggestion for continued work in environmental research collaborations is to recognise the collaboration process as a challenge in itself. Collaborative processes run more smoothly when there are early discussions about how and what each partner wants to achieve. At this stage, it is important to initiate an open and informal discussion to form a basic trust. This is not achieved in one day. It requires a time investment from all partners and recognition of the strength that comes from bringing together different competencies together to solve the environmental problems of our day.

Another suggestion is to acknowledge that theories and models are ideals that do not always deliver what is promised. Individuals will make the most of this and will likely form their ideas about what models like the triple helix mean. The will and drive to collaborate are important factors. Working towards common goals such as improvement of the environment motivates and brings together participants. It is also important to acknowledge the different time perspectives, cultures, financial structures, goals and different perceptions of knowledge.

This thesis is also relevant for research policy. The interaction between science and society will continue to be a topic for research policy. In particular so, on the national level where science is measured and weighed against its potential usefulness. Research policy influences all disciplines to some extent. Environmental science is no exception, and authorities that enforce legislation directly targets environmental issues. Scientific input on the large scale environmental problems of today also creates an area where science and policy meet (Miller, 2001). Sarewitz, for example, warns that science itself can become highly political especially regarding environmental controversies (Sarewitz, 2004).

Considering environmental policy there has been a call for a more holistic approach that includes society in the scientific process by collaboration. Environmental issues as such must be understood as inseparable from societal

issues. It is problematic when environmental issues are defined solely as technical as this exclude parts of society (Cortner, 2000). The demand from policy makers for knowledge that is useful for decision-making in environmental problems and the supply of knowledge from scientists is an additional challenge (McNie, 2007). This can be an important way for scientists to reach out with their research and influence policy. On the other hand, this can lead to a relation where scientists are providers of knowledge demanded from policy actors.

The usefulness and relevance of research is difficult to predict, but this thesis has shown that scientists do reflect upon this. Care needs to be taken when categorising some research as useful and other research as less useful. Basic and applied sciences, if one supports this categorisation, should not be measured against each other with regards to their potential usefulness. New theoretically loaded buzzwords will continue to enter research policy, and in the end, scientists react to these trends in their everyday working life. All research need not be collaborative but the environmental problem should be in focus.

7.4 A final reflection at the end of a journey

The research presented in this thesis shows that environmental scientists are not isolated in an ivory tower. The research processes were situated on the blurring boundaries between science and society. This research provides knowledge about how environmental scientists work and perceive collaboration and the relevance of research. In turn, this has also provided insights into how non-academic participants perceive the scientists and their research. As such, the research is not concerned with non-collaborating scientists, which might be interesting in its own right. There might be scientists that do not collaborate and do not want to.

Researching collaborative processes and being part of these was also a learning process for me. I had to learn how to navigate the boundaries between disciplines and sectors and at the same time conduct research. There was also an advantage of being a social scientist in a natural science environment. It has been a road full of interesting discussions and sometimes quarrels about what science is or is not. One week might have been devoted to digging in landfills and sorting waste, followed by a public lecture the following week. Another week I might have been studying pragmatist philosophers, teaching students in Thailand about the circular economy or interviewing participants from industry. To grow as a Ph.D. candidate means to be challenged along the way. Appreciating and throwing oneself into a completely different area of research is one way to establish new frontiers. Social scientists need to get their hands dirty!

This intriguing process has led to the final understanding of the term this thesis set out to investigate: triple helix. It became apparent that this existed in the everyday conversation and collaboration as something different from what it was originally intended to be. It became a manifestation of the engagement between scientists and partners outside of academia. The complexity of interaction between science and society has given rise to new ideas that include additional helixes and introduces a Mode 3 than a Mode 2. These bring along an important lesson by not limiting knowledge production to particular participants or sectors.

Putting the environment as a framework for this and solving environmental problems through an increasingly democratic research process, is a refreshing thought. The future challenges for the environment call for inclusive solutions with the realisation that we are all crew members of Spaceship Earth. What then is the role of environmental scientists to solve these challenges? How far should the third mission be extended? The freedom and investment that society has given scientists come with responsibilities. However, we cannot force the relevance of research and see it as a silver bullet for all future challenges. We must not forget the unpredictability of results. A division between applied and basic science is blurred in the long-term perspective, and the usefulness of such should not be forced. Further, the democratisation of the research process, through collaboration, would, in turn, provide the relevance that is sought after.

There were many examples encountered during the long research process that highlighted the importance of openness and informality. In this, there is a phenomenon that is hard to study empirically. It is people that connect with each other and sustain their contacts in a wide network. These are the true boundary spanners. Abstract skills such as the ability to listen, to be humble and honest, seems to be important for all aspects of collaboration. This thesis shows the importance of dialogue, which might well be the key to solve the puzzle of collaboration.

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Appendix A: Interview guides, survey and list of interviewees for papers I-III

Paper I: Interview guide

General questions about the project

What was the STInno project?
Was the aims of the STInno-project fulfilled?
What could have been done better?
What problems occurred?
What went well?
What was the effect of the EU leadership?
What was the use of Triple Helix and cluster theories?

Networks, communication and trust

What platform of communication was most common?
What people did you have most contact with?
Did you feel you could rely on partners in other sectors and countries?
How was the collaboration within countries compared to between?
How was the collaboration within sectors compared to between?
What use is the network now after the project?

Goal oriented questions

People are more likely to take responsibility for their own action than be defensive?
The common goals in the project are more important than your own goals in the project?
You feel you have been part of the decision making during the project?
The project promotes cooperation and learning?

Summing up

Anything to add?

Paper I: Questionnaire

General questions

What is your nationality? (optional)
What sector do you affiliate with? (University, Public, Business)

Open ended questions

How would you describe the type of collaboration adopted by STInno?

What main events have defined STInno most? (changes, meetings etc.)

Has the STInno network been useful outside the project? If yes describe how

Likert scale questions (Strongly agree/Agree/Neither agree nor disagree/Disagree/Strongly disagree)

General

Project results are what I expected

Progress is still being made in the project

Models of innovation creation (Triple Helix, Cluster)

These models are more talk/buzzwords than practice

These models have been useful for everyday work

Generally about network, communication, trust and social capital

The STInno network has been useful outside the project

Trust has developed between countries more so than within

Trust has developed between different sectors more so than within

Some sectors worked more together than others

Problems have been solved within rather than between countries

Problems have been solved within rather than between sectors

Use of networks (bonding/bridging- within countries or between)

STInno has been able to form cross sector collaboration

The network within countries has become stronger

The network between countries has become stronger

In STInno, it has been more important to have a strong small network than a large weak one

You feel that you can ask help from someone in another country our sector

STInno has extended its results beyond its own network

Power / Theories / Models

What you do for the project is what you think is right to do
People are more likely to take responsibility for their own action than be defensive
The common goals in the project are more important than your own goals in the project
You feel you have been part of the decision making during the project
The project promotes cooperation and learning
The project environment promotes cooperation rather than rivalry

Paper II: Interview guide (translated from Swedish)

Collaboration (general)

How do you perceive the conditions for environmental technology in the region?
How can the environmental technology sector benefit from collaboration between sectors?
What possibilities for collaboration are there for you?
In what circumstances have you had contact with other sectors?
What can the (two) other sectors provide in a collaboration with you?
Who is the initiator for such collaborations?
How are the (two) other sectors different from yours?
How does this affect collaboration with these sectors?
What adjustments do the sectors need to do?

Collaboration (specific)

Can you give an example of collaboration with other sectors?
How and why did this collaboration start?
What worked out good/bad?
Is this common for collaboration in general or do you want to add something?
Have you gained new contacts through collaboration and how have these been an asset to you?
Have these individuals been able to help you outside of the collaboration?
Do you feel that you can trust the other participants when collaborating?

Conditions and future work

What can improve future collaboration?
What factors are important for a good collaboration?
What needs are there for future collaboration and what do you want to get out of this?
What does triple helix mean in the context of collaboration?
What is a good collaborator and what practical knowledge does such a person need?

Other questions

Anything to add?

Paper III: Interview guide (translated from Swedish)

About the meeting

Has the information presented during the meeting been used in your organisation?
Did it give any insights into what the circular economy is?

Waste

What possibilities do you see regarding a better sorting of waste?
Any ideas on how waste can become a resource?
What challenges exist when looking for a better sorting of waste?

Circular economy

Is the circular economy concept used in your organization?
Did the meeting work as an entry point to understand the circular economy?
Did the meeting work as a forum for discussing ideas about waste?
Does your organisation use the same type of knowledge?
Does such a report work as a way to translate research into practice?

Project report

Have you read the report?
Are the results relevant for you?
Was the information comprehensible?

Knowledge

What change in knowledge do you have to do in your organisation?
What knowledge is needed in your organization?

Summing up

Anything to add?

List of interviewees

Paper I

Interviewee #	Sector*
1	Research
2	Public
3	Business
4	Public
5	Business

*Countries or position are not used in this table as this could threaten the anonymity due to the small size of the project

Paper II

Interviewee #	Sector*	Position
1	Business	CEO
2	University	External relations officer
3	Business	Executive president
4	Public	Chief executive
5	Public	Project leader
6	Business	Technical supervisor
7	Business	Consultant

Paper III

Interviewee #	Sector*	Position
1	Business	Coordinator
2	Business/Public*	Real estate manager
3	Business	Consultant
4	Business	Project leader/developer
5	Business	General manager
6	Business	Coordinator
7	Business/Public*	Garbage collector
8	Business	Consultant
9	Business	Environmental manager
10	Public	Innovation coordinator
11	Business/Public*	Environmental coordinator
12	University	Education coordinator

13	Public	Chief executive of sanitation
14	Business	Technician
15	Business	Sales representative

*Business partly or fully owned by the public sector

Appendix B: Supplementary material for Paper V

Supplementary material for: *Exploring the attitudes to societal relevance: The effects on reflection and choice of research among environmental scientists*

Abstract

This document includes further details on the statistical analyses presented in the main text. All analyses were performed using R version 3.2.2 (R Core Team, 2015) except Visualization of similarities (VOS) analyses that were performed using VOSviewer version 1.6.3 (van Eck and Waltman, 2010).

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1 Descriptives

This section provides descriptive analyses of the variables included in the questionnaire. Some of the variables were recoded to improve analytical clarity.

1.1 Background informations

Frequency distribution of the items included in the A section of the questionnaire. Note: the numbers may not to add up to the number of respondents due to missing observations.
N. of respondents: 307.
Gender: 170, male; 135, female.
Position: 25, staff/administrator; 118, PhD student; 45, researcher/postdoc; 38, lecturer; 36, associate professor (*docent*); 45, professors.
Years of experience within academia: 31, 2 years or less; 88, 3–5 years; 69, 6–10 years; 119, more than 10 years.
Discipline: 252, environmental science; technology and/or engineering; 55, other.
Years of experience outside academia: 96, less than a year; 99, 1–2 years; 56, 3–5 years; 29, 6–10 years; 26, more than 10 years.
Planned/conducted research with partners outside academia: 235, yes; 71, no.
University encourages collaborations outside academia: 20, not at al; 141, yes-rarely; 76, yes-occasionally; 31, yes-frequently.

1.2 Definition of the usefulness of academic research

"Research is most useful when . . . " (frequency of definitions ranked first):

- 29, (A) it produces new research methods, instruments and designs that will advance scientific research.
- 65, (B) it creates new products, patents, licenses, processes and services that will bring about economic growth.
- 95, (C) it produces new knowledge that will advance scientific research through education and publication of scientific findings.
- 87, (D) it provides findings that can influence policymakers and industry actors in making decisions that will be beneficial for society.
- 30, (E) it leads to collaboration between different actors in society resulting in new networks and research opportunities.

1.3 Questionnaire sections C–F

Figure 1 shows the frequency distribution of the items included in the sections C, D, E, and F of the questionnaires. Note that some variables were reversed in order to build clearer constructs for the PLSPM analysis.

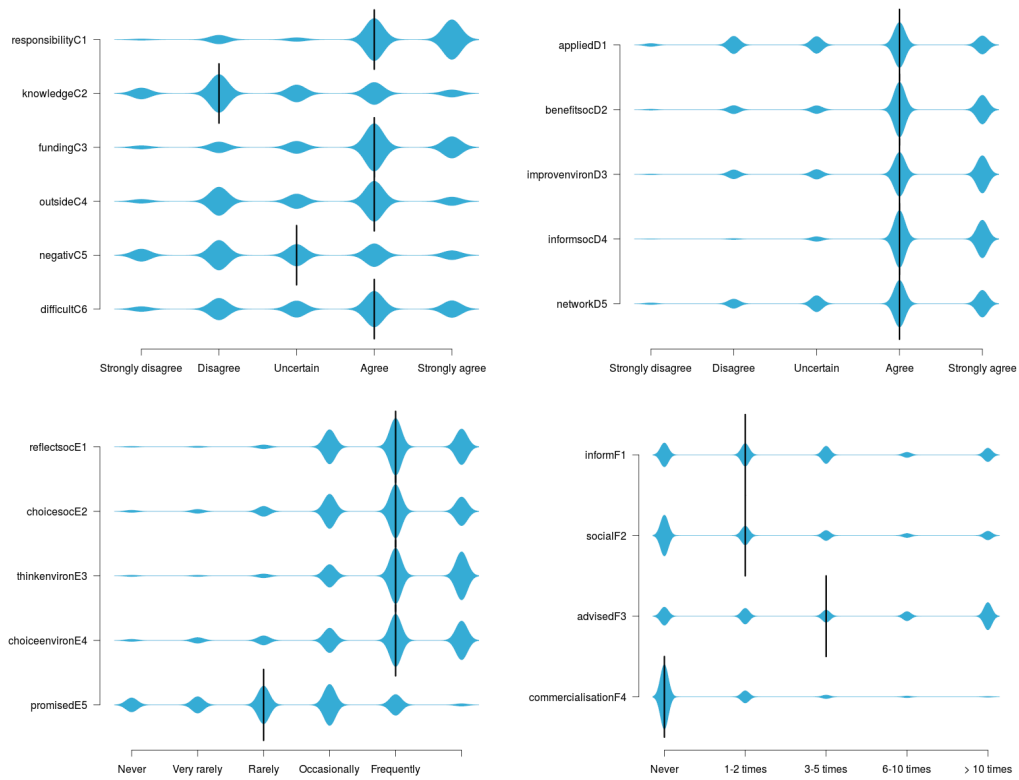

Figure 1: Distribution of the variables included in the questionnaire (C–F parts). Shaded areas represent density curves and vertical bars show the median for each variable.

2 PLSPM analysis

The models below were based on partial least square path modelling (PLSPM) approach (Esposito Vinzi and Russolillo, 2013; Wold, 1975). The *plspm* R package (Sanchez, 2013) was used for all estimations.

2.1 Model 1: Choice of the research

The Pressure to produce relevant research construct (*pressure*) was based on the *fundingC3* and *promisedE5* variables ($DG\rho = 0.76$, $1^{st}eig. = 1.22$, $2^{nd}eig. = 0.79$). The Attitude to collaboration construct (*collaboration*) was based on the *plannedA7*, and *networkD5* variables ($DG\rho = 0.71$, $1^{st}eig. = 1.37$, $2^{nd}eig. = 0.90$). The Research experience construct (*experience*) was based on the *univpositionA2* and *experianceA4* variables ($DG\rho = 0.87$, $1^{st}eig. = 1.55$, $2^{nd}eig. = 0.45$). The Attitude to societal relevance construct (*soc.relevance*) was based on the *appliedD1*, *benefitsocD2*, *improvenvironD3*, and *B1D* variables ($DG\rho = 0.82$, $1^{st}eig. = 2.19$, $2^{nd}eig. = 0.90$). The Reflection construct (*reflection*) was based on the *reflectsocE1* and *thinkenvironE3* variables ($DG\rho = 0.81$, $1^{st}eig. = 1.36$, $2^{nd}eig. = 0.64$). The Choice of the research construct (*choice*) was based on the *choicesocE2* and *choiceenvironE4* variables ($DG\rho = 0.85$, $1^{st}eig. = 1.48$, $2^{nd}eig. = 0.52$). Table 1 shows a summary of the resulting outer model while Table 2 presents a summary of the direct and indirect effects estimates for model 1.

Variable	Construct	Weight	Loading	Communality	Redundancy
fundingC3	pressure	0.745	0.858	0.736	0.000
promisedE5	pressure	0.526	0.686	0.471	0.000
prevexpA6	collaboration	0.291	0.426	0.182	0.000
plannedA7	collaboration	0.234	0.498	0.248	0.000
networkD5	collaboration	0.826	0.920	0.846	0.000
univpositionA2	experience	0.909	0.992	0.984	0.000
experianceA4	experience	0.151	0.651	0.424	0.000
appliedD1	soc.relevance	0.492	0.869	0.755	0.079
benefitsocD2	soc.relevance	0.280	0.765	0.586	0.061
improvenvironD3	soc.relevance	0.342	0.805	0.648	0.067
B1D	soc.relevance	0.196	0.424	0.180	0.019
reflectsocE1	reflection	0.588	0.814	0.663	0.090
thinkenvironE3	reflection	0.623	0.837	0.700	0.096
choicesocE2	choice	0.559	0.849	0.720	0.341
choiceenvironE4	choice	0.603	0.872	0.760	0.360

Table 1: Model 1 outer model summary.

2.2 Model 2: Dissemination

The Attitude to collaboration construct (*prevexpA6*) was based on the *plannedA7*, and *networkD5* variables ($DG\rho = 0.74$, $1^{st}eig. = 1.47$, $2^{nd}eig. = 0.88$). The Research experience construct (*experience*) was based on the *univpositionA2* and *experianceA4* variables ($DG\rho = 0.89$, $1^{st}eig. = 1.60$, $2^{nd}eig. = 0.40$). The Reflection construct (*reflection*)

Relationships	Direct	Indirect	Total
pressure → collaboration	0.000	0.000	0.000
pressure → experience	0.000	0.000	0.000
pressure → soc.relevance	0.220	0.000	0.220
pressure → reflection	0.000	0.041	0.041
pressure → choice	0.195	0.046	0.242
collaboration → experience	0.000	0.000	0.000
collaboration → soc.relevance	0.200	0.000	0.200
collaboration → reflection	0.243	0.037	0.280
collaboration → choice	0.000	0.187	0.187
experience → soc.relevance	0.000	0.000	0.000
experience → reflection	0.144	0.000	0.144
experience → choice	0.010	0.086	0.096
soc.relevance → reflection	0.186	0.000	0.186
soc.relevance → choice	0.100	0.111	0.211
reflection → choice	0.597	0.000	0.597

Table 2: Summary of the estimated direct and indirect effects for model 1.

was based on the *reflectsocE1* and *thinkenvironE3* variables ($DG\rho = 0.83$, $1^{st}eig. = 1.43$, $2^{nd}eig. = 0.57$). The Dissemination construct (*dissemination*) was based on the *informF1*, *advisedF3*, and *commercialisationF4* variables ($DG\rho = 0.81$, $1^{st}eig. = 1.75$, $2^{nd}eig. = 0.80$).

Table 3 shows a summary of the resulting outer model while Table 4 presents a summary of the direct and indirect effects estimates for model 2.

Variable	Construct	Weight	Loading	Communality	Redundancy
prevexpA6	collaboration	0.373	0.552	0.305	0.000
plannedA7	collaboration	0.548	0.791	0.625	0.000
networkD5	collaboration	0.492	0.733	0.537	0.000
univpositionA2	experience	0.645	0.928	0.861	0.000
experianceA4	experience	0.468	0.858	0.736	0.000
reflectsocE1	reflection	0.775	0.938	0.881	0.075
thinkenvironE3	reflection	0.382	0.714	0.510	0.044
informF1	dissemination	0.508	0.838	0.702	0.329
advisedF3	dissemination	0.505	0.862	0.742	0.348
commercialisationF4	dissemination	0.257	0.541	0.293	0.137

Table 3: Model 2 outer model summary.

Relationships	Direct	Indirect	Total
collaboration → experience	0.000	0.000	0.000
collaboration → reflection	0.269	0.000	0.269
collaboration → dissemination	0.286	0.040	0.325
experience → reflection	0.077	0.000	0.077
experience → dissemination	0.521	0.011	0.532
reflection → dissemination	0.148	0.000	0.148

Table 4: Summary of the estimated direct and indirect effects for model 2.

3 Analysis of the open questions

A *corpus* is a collection of text documents representing the basic dataset for textual analysis. We considered each answer to the open question *G1* as an independent text. Over a total of 95 answers, 93 were in English and were included in the corpus while two were in Swedish and were excluded from the analysis to build a consistent collection.

3.1 The Visualization of similarities approach

The Visualization of similarities (VOS) approach was originally developed to map bibliometric networks but can be applied to any corpus of texts. The VOS mapping technique is closely related to multidimensional scaling while clustering is modularity-based. The VOS algorithm provides a unified approach to mapping and clustering and is implemented in the VOSviewer software (version 1.6.3 used here). Further details can be found in van Eck and Waltman (2010) and Waltman et al. (2010).

3.2 Estimation of the applied-science orientation construct

We estimated a variable reflecting the applied-science orientation of each respondent using non-linear iterative partial least squares (NIPALS) principal component analysis (Wold, 1975). The construct was based on the *C1*, *C5*, *D1*, *D2*, *D3*, *basic*, and *applied* variables. The last two variables were based on the *B1* question, with *basic* taking one if *B1* = (A) or *B1* = (C) and zero otherwise while *applied* took one if *B1* = (B) or *B1* = (D) and zero otherwise. The resulting construct had an eigenvalue of 3.06 and explained 43.8% of the data variance. The corresponding loadings are showed in Table 5.

Variable	Loadings
responsibilityC1	0.35
negativC5	-0.28
appliedD1	0.42
benefitsocD2	0.39
improvenvironD3	0.40
basic	-0.40
applied	0.39

Table 5: Applied-science orientation construct loadings.

4 Further analyses

We explored the effect of the background variables included in the A section of the questionnaire on the *reflection*, *choice* and *dissemination* constructs, defined as in Section 2. All predictors weakly or not affected the *reflection* and *choice* outcomes, leading to non significant models. The only outcome that appeared to significantly depend on background variables was the *dissemination* one (Tab. 6). Results were overall little surprising. PhD students and young researchers did less dissemination activities than the reference category (university staff/administrators) while professors did significantly more. Dissemination activities increased with experience within and, to a lesser extent, outside academia. Finally, respondent that planned or conducted research in collaboration with partners outside the academia participated significantly more in dissemination activities.

	Estimate	Std. Error	t-value	p-value
(Intercept)	-1.015	0.357	-2.846	0.005
gender: Female	-0.012	0.118	-0.100	0.920
position: PhD student	-0.764	0.245	-3.114	0.002
position: Researcher/postdoc	-0.590	0.251	-2.350	0.019
position: Lecturer	0.192	0.265	0.723	0.470
position: Associate professor	0.405	0.268	1.514	0.131
position: Professor	0.885	0.270	3.276	0.001
uni.type: General universities	-0.135	0.123	-1.095	0.274
experience: 3-5 years	0.519	0.211	2.461	0.014
experience: 6-10 years	0.512	0.235	2.176	0.030
experience: $>$ 10 years	0.773	0.270	2.864	0.004
discipline: Environmental science	0.006	0.151	0.037	0.970
ext.experience: 1-2 years	0.167	0.143	1.166	0.244
ext.experience: 3-5 years	0.343	0.170	2.017	0.045
ext.experience: 6-10 years	0.290	0.210	1.381	0.168
ext.experience: More than 10 years	0.484	0.225	2.152	0.032
planned: Planned	0.689	0.147	4.674	0.000
R^2	0.500			
$F(16,284)$	17.740			0.000

Table 6: OLS estimates on the dissemination construct. Reference categories are: gender: male; position: staff; university type: technical universities; academic work experience: 2 years or less; discipline: other; external work experience: less than one year; planned/conducted external research: not planned. The *A8* question was excluded from the analysis due to a high number of missing observations.

5 Questionnaire

A copy of the questionnaire used in the research is appended at the end of the document.

Linnæus University

Questionnaire about the role of environmental research in society

Hello!

We would greatly appreciate your participation in this questionnaire aimed at members of research groups/centres in environmental science, technology and related disciplines at Swedish universities. The main aim of this questionnaire is to find out more about how scientists reflect upon the relevance and impact of their research on society and the environment.

Some scholars argue that there is an increasing pressure to produce knowledge that will directly benefit society. Further, it is argued that this is increasingly done in collaboration with partners outside the university setting. This research aims to contribute to these studies of the contemporary state of knowledge production. This study is part of a PhD project in environmental science conducted by Joacim Rosenlund at Linnaeus University in Kalmar.

Estimated completion time is about 10 minutes and your participation is voluntary. The collected material will only be used for scientific purposes in accordance to the ethical guidelines established for the humanities and social sciences. The answers will be processed in such a way that the anonymity of participants will be guaranteed. Your participation would greatly benefit our research! We would appreciate you participation before November 15th.

Any questions regarding this survey can be directed to: peter.notini.extern@lnu.se

With kind regards

Peter Notini, Project assistant (peter.notini.extern@lnu.se)

Joacim Rosenlund, PhD student (joacim.rosenlund@lnu.se)

Department of Biology and Environmental Science, Linnaeus University, Kalmar

Linnæus University

Part A: Background information

A.1 - Gender

Male
Female

A.2 - What postion do you have?

A.3 - Please indicate which university you are currently employed at.

A.4 - How many years have you been working with academic research?

Less than a year
1-2 years
3-5 years
6-10 years
More than 10 years

A.5 - Within which discipline do you conduct research?

Environmental science, technology and/or engineering
If other, please specify

A.6 - How many years of work experience do you have from job sectors other than academia?

Less than a year
1-2 years
3-5 years
6-10 years
More than 10 years

A.7 - Have you ever planned/conducted research in collaboration with partners outside academia (industry, companies, public sector etc.)?

- Yes
- No

A.8 - Does the management of your university encourage you to pursue collaboration with partners outside academia (industry, companies, public sector etc.)?

- Yes, frequently
- Yes, occasionally
- Yes, rarely
- Not at all
- Don't know

Linnæus University

Part B: Defining the usefulness of academic research

In this part, we want you to rank five different definitions (A-E) about how research is made useful. Rank them against each other in descending order where no. 1 indicates your most preferred definition whilst no. 5 indicates your least preferred definition.

Research is most useful when…

1 (A)… it produces new research methods, instruments and designs that will advance scientific research.

2 (B)… it creates new products, patents, licenses, processes and services that will bring about economic growth.

3 (C)… it produces new knowledge that will advance scientific research through education and publication of scientific fin

4 (D)… it provides findings that can influence policymakers and industry actors in making decisions that will be beneficial t

5 (E)… it leads to collaboration between different actors in society resulting in new networks and research opportunities.

Linnæus University

Part C: Attitudes towards research and science in general

Indicate to which degree that you agree or disagree with the following statements.

	Stongly agree	Agree	Undecided	Disagree	Strongly disagree	Don't know
C.1 - Science has a responsibility to produce research that benefits society.						
C.2 - Science should mainly produce basic knowledge for the advancement of the discipline.						
C.3 - When applying for funding you have to convince research funding agencies that you can reach applied results.						
C.4 - Research is often conducted together with actors outside academia.						
C.5 - The need to produce research of relevance for society has negatively influenced academic freedom.						
C.6 - It's difficult to find funding for the research you would want to conduct.						

Part D: Attitudes regarding the societal and environmental relevance of research

Indicate to which degree that you agree or disagree with the following statements.

	Strongly agree	Agree	Undecided	Disagree	Strongly disagree	Don't know
D.1 - It's important to reach results that can be applied in practice.						
D.2 - It's important to reach results that benefits society in general.						
D.3 - It's important to reach results that specifically can improve the environment.						
D.4 - It's important to inform society about my research.						
D.5 - It's important for my research to have a network of collaborators outside the university setting.						

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Part E: Reflecting upon the relevance of research

Indicate how frequently…

	Very frequently	Frequently	Occasionally	Rarely	Very rarely	Never	Don't know
E.1 - …you reflect on the impact of your research on society.							
E.2 - …your choice of research has been affected by its potential impact on society.							
E.3 - …you think about the environmental impact of your research.							
E.4 - …your choice of research has been affected by the potential impact it could have on the environment.							
E.5 … you have promised more applied results than you have provided.							

Part F: Activities for dissemination of scientific results

Indicate how often you have…

	Never	1-2 times	3-5 times	6-10 times	More than 10 times	Don't know
F.1 - …informed media about your research (TV, newspaper, etc.).						
F.2 - …used social media to inform about your research (blog, Facebook, Twitter).						
F.3 - …advised or consulted the public or the private sector on subjects related to your research.						
F.4 - …taken part in commercialisation activities (new patents, companies or products).						