Assessing Transdisciplinary Research in Sustainability Science

Von der Fakultät Nachhaltigkeit
der Leuphana Universität Lüneburg zur Erlangung des Grades

Doktorin der Staatswissenschaften
– Dr. rer. pol. –

genehmigte Dissertation von Stephanie Verena Jahn
geboren am 21.02.1986 in Mindelheim (Deutschland)

Eingereicht am: 17. April 2023

Mündliche Verteidigung (Disputation) am: 17. August 2023

Erstbetreuer und Erstgutachter:	Prof. Dr. Jens Newig
Zweitbetreuer und Zweitgutachter:	Prof. Dr. Daniel J. Lang
Drittgutachterin:	Prof. Dr. Flurina Schneider

Die einzelnen Beiträge des kumulativen Dissertationsvorhabens sind inkl. des Rahmenpapiers wie folgt veröffentlicht:

Jahn, Stephanie, Jens Newig, Daniel J. Lang, Judith Kahle, and Matthias Bergmann. 2022. Demarcating transdisciplinary research in sustainability science – Five clusters of research modes based on evidence from 59 research projects. Sustainable Development, 30(2), 343-357.

Newig, Jens, Stephanie Jahn, Daniel J. Lang, Judith Kahle, and Matthias Bergmann. 2019. Linking modes of research to their scientific and societal outcomes. Evidence from 81 sustainability-oriented research projects. Environmental Science and Policy 101, 147-155.

Juerges, Nataly and Stephanie Jahn. 2020. German forest management stakeholders at the science-society interface: Their views on problem definition, knowledge production and research utilization. Forest Policy and Economics 111, 102076.

Veröffentlichungsjahr: 2023

Table of contents

Acknowledgements

First and foremost, I am grateful to my academic supervisors, Prof. Dr. Jens Newig and Prof. Dr. Daniel J. Lang for their continuous support and their faith in my abilities, even when I did not believe in them myself. I am very thankful for the opportunity to participate in the unique project "Modes of sustainability-related research in comparison (MONA)". Thank you for opening this exciting field of research to me, for sharing your knowledge, craft, and strategy, for guiding and challenging me. I also like to thank Prof. Dr. Matthias Bergmann for sharing his outstanding experience in the field. Moreover, I would like to especially express my gratitude to my research partner in the MONA project Judith Kahle. Thank you for the great teamwork, the mutual empowerment and friendship. Furthermore, I would like to thank my co-author Dr. Nataly Jürges for the pleasant co-working and for giving me an insight into the field of forest research. Great thanks are also due to Prof. Dr. Flurina Schneider for taking on the role of external examiner on the doctoral committee.

Furthermore, I am grateful to Leuphana University of Lüneburg for being an exceptionally inspiring environment and to Leuphana Graduate School for a six-month scholarship. Beyond that, this work would not have been possible without the respondents who participated in the studies. I am very thankful to everyone who invested their time to support the advancement of knowledge on transdisciplinary research in sustainability science.

Many fantastic people crossed my path on this journey. In particular, I would like to thank Franziska Steinbrügge, Dr. Marie Weiß, Maria Brück, Johanna Coenen, Dr. Michael Rose, Dr. Nicolas Jager, Dr. Esther Meyer, Dr. Benedetta Cotta, Dr. Lotte Lutz, Dr. Fabienne Gralla, Lena Theiler and Dr. Elisa Kochskämper for invaluable exchange, support and companionship. I would especially like to thank Anna Sundermann for many uplifting conversations and the numerous amazing online and offline writing sessions. A big thank you also goes to Dr. Johannes Schiller, for becoming my mentor during the last few meters.

Finally, I would like to thank Zora Asse, Franz Rosenberger, Sandra Schwartz, my parents Gertrud and Dieter Jahn and my sister Anna Jahn for their love and support in challenging times and for not stopping to encourage me.

Abstract

Given the complex, dynamic, and urgent problems that sustainability science addresses, research approaches are required that not only improve the understanding of sustainability challenges, but also to support action for sustainable development. In this context, transdisciplinary research has established as an approach that aims not only to generate new knowledge, but also to promote the societal relevance and application of research findings through direct collaboration of scientists and societal stakeholders from different fields in integrative research processes. Despite its increasing prevalence in the field, there remains a gap between theoretical ideal-typical models of transdisciplinary research and its actual application within sustainability science. While scholars generally agree that transdisciplinary research is societally effective, there is scattered and partly conflicting evidence on which aspects of transdisciplinary research foster societal impact. Moreover, the extent to which transdisciplinary research contributes to scientific progress is largely unexplored.

This thesis aims to contribute to a better understanding of the actual implementation of transdisciplinary research in sustainability science. Following three aims, this work likes to (1.) contribute to the measurability of transdisciplinary research processes as well as their societal and academic outputs and impacts, to (2.) demarcate transdisciplinary research from other modes of research in sustainability science and to (3.) identify and examine the determinants that shape the contribution of transdisciplinary research to societal action for sustainable development and to scientific knowledge production.

To serve these aims a mixed methods approach is applied that combines strong quantitative elements with in-depth qualitative analyses that integrate the perspectives of practitioners. This thesis provides a broad set of indicators to describe and assess transdisciplinary research that translate theoretical concepts form transdisciplinarity theory into observable variables. The indicators offer a holistic perspective on transdisciplinary research by representing research mode characteristics, societal as well as scientific outcomes of research projects and their specific context.

To theoretically demarcate transdisciplinary research from other forms of research, a narrative literature review first elaborates the differences between 'normal science', political use of scientific knowledge and transdisciplinarity in their underlying logics of problem definition, knowledge production and research utilization. Subsequently, these concepts were compared with perspectives and expectations of practitioners in the forest sector on integrative research

settings, showing that practitioner perspectives align the most with conceptualizations of political use of scientific knowledge.

Moreover, a cluster analysis of data from 59 research projects identified five research modes that empirically demarcate ideal-typical transdisciplinary research from other research modes within sustainability science: (1) purely academic research, (2.) practice consultation, (3.) selective practitioner involvement, (4.) ideal-typical transdisciplinary research and (5.) practice-oriented research. Based on this finding, transdisciplinary research can be characterized as an intensive, but balanced involvement of practitioners. It incorporates not only the needs and goals of the practitioners but also their norms and values. Ideal-typical transdisciplinary research goes beyond mere consultatory research approaches and must be distinguished from what is conceptualized as applied research.

Regression analysis of 81 research projects and statistical group comparisons of the five research mode clusters show that societal and academic outputs and impacts vary with specific project characteristics and combinations of project characteristics defined as research modes. The findings indicate that more interactive research modes reach more societal impacts. In particular, the involvement of practitioners in early project phases and the targeted dissemination of the research results positively affect societal impacts. This finding also aligns with practitioner expectations on integrative research and research utilization, provided by qualitative analysis. Moreover, the quantitative results show that scientific outputs and impacts decrease with the intensity of interactions, indicating a trade-off between societal and scientific outcomes and impacts.

Overall, the empirical results of this thesis support the claimed effectiveness of transdisciplinary research in providing societally relevant, applicable knowledge and encourage further funding of transdisciplinary research by funding agencies. The relationships discovered in this study between research mode characteristics and societal as well as academic outputs and impacts can help researchers design and reflect on their research and can inform funding agencies in the design of project calls and research programs. However, the observed lower academic outputs and impacts of more integrative research modes raise the question of how to further strengthen the systematic documentation and accessibility of the results of transdisciplinary sustainability research. Additionally, the observed trade-off between societal and academic impacts of transdisciplinary research highlights the need for strategies to mediate between the dual aim of transdisciplinary research to contribute to societal problem solving and scientific knowledge production.

Keywords: transdisciplinarity, sustainability science, transdisciplinary research, societal impact, scientific impact, research mode, research evaluation

Deutsche Zusammenfassung

Transdisziplinäre Forschung in den Nachhaltigkeitswissenschaften erfassen und bewerten

Angesichts der komplexen, dynamischen und drängenden Krisen, mit denen sich die Nachhaltigkeitswissenschaften befassen, sind Forschungsansätze erforderlich, die nicht nur ein besseres Verständnis von Mensch-Umwelt-Verhältnissen schaffen, sondern auch aktives Handeln für eine nachhaltige Entwicklung unterstützen. In diesem Zusammenhang hat sich die transdisziplinäre Forschung als ein Ansatz etabliert, der nicht nur darauf abzielt, neues Wissen zu generieren, sondern auch die gesellschaftliche Relevanz und Anwendung von Forschungsergebnissen durch die direkte Zusammenarbeit von Wissenschaftler*innen und gesellschaftlichen Akteuren aus verschiedenen Bereichen in integrativen Forschungsprozessen zu fördern. Trotz der zunehmenden Anwendung von transdisziplinärer Forschung, besteht nach wie vor eine Kluft zwischen theoretischen idealtypischen Modellen und ihrer tatsächlichen Umsetzung in den Nachhaltigkeitswissenschaften. Während sich die Forschung im Allgemeinen einig ist, dass transdisziplinäre Forschung gesellschaftlich wirksam ist, gibt es nur vereinzelte und teilweise widersprüchliche Belege dafür, welche konkreten Aspekte der transdisziplinären Forschung gesellschaftliche Wirkungen fördern. Darüber hinaus ist das Ausmaß, in dem transdisziplinäre Forschung zum wissenschaftlichen Fortschritt beiträgt, weitgehend unerforscht.

Diese Doktorarbeit soll zu einem besseren Verständnis der tatsächlichen Umsetzung transdisziplinärer Forschung in den Nachhaltigkeitswissenschaften beitragen. Die Arbeit verfolgt drei Ziele: (1.) einen Beitrag zur Messbarkeit transdisziplinärer Forschungsprozesse sowie ihrer gesellschaftlichen und wissenschaftlichen Ergebnisse und Wirkungen zu leisten, (2.) transdisziplinäre Forschung von anderen Forschungsansätzen in den Nachhaltigkeitswissenschaften abzugrenzen und (3.) die Determinanten zu identifizieren und zu untersuchen, die den Beitrag transdisziplinärer Forschung zu gesellschaftlichem Handeln für eine nachhaltige Entwicklung und zur wissenschaftlichen Wissensproduktion prägen.

Um diese Ziele zu erreichen, wird ein Mixed-Methods-Ansatz angewandt, der starke quantitative Elemente mit in die Tiefe gehenden, qualitativen Analysen kombiniert, die auch die Perspektiven von Praktiker*innen einbeziehen. Diese Arbeit liefert ein umfassendes Indikatorenset zur Beschreibung und Bewertung transdisziplinärer Forschung, das theoretische Konzepte aus der Transdisziplinaritätstheorie in beobachtbare Variablen umsetzt. Die Indikatoren bieten eine ganzheitliche Perspektive auf transdisziplinäre Forschung, indem sie die Charakteristika des

Forschungsmodus, die gesellschaftlichen und wissenschaftlichen Ergebnisse und Wirkungen von Forschungsprojekten und deren spezifischen Kontext abbilden.

Um transdisziplinäre Forschung theoretisch von anderen Forschungsansätzen abzugrenzen, werden in einer narrativen Literaturanalyse zunächst die Unterschiede zwischen "Normalwissenschaft", politischer Nutzung wissenschaftlichen Wissens und Transdisziplinarität in den ihnen zugrunde liegenden Logiken der Problemdefinition, Wissensproduktion und Forschungsnutzung herausgearbeitet. Anschließend werden diese Konzepte mit den Perspektiven und Erwartungen von Praktiker*innen im Forstsektor an integrative Forschungssettings verglichen. Dabei zeigt sich, dass die Perspektiven der Praktiker*innen am stärksten mit dem Konzept der politischen Nutzung wissenschaftlichen Wissens übereinstimmen.

Darüber hinaus identifiziert eine Clusteranalyse der Daten von 59 Forschungsprojekten fünf Forschungsmodi, die die idealtypische transdisziplinäre Forschung empirisch von anderen Forschungsmodi innerhalb der Nachhaltigkeitswissenschaften abgrenzen: (1.) rein akademische Forschung, (2.) Beratung durch die Praxis, (3.) selektive Praxiseinbindung, (4.) idealtypische transdisziplinäre Forschung und (5.) praxisorientierte Forschung. Ausgehend von diesen Ergebnissen lässt sich transdisziplinäre Forschung als geprägt von einer intensiven, aber ausgewogenen Einbindung von Praktiker*innen charakterisieren. Sie bezieht nicht nur die Bedürfnisse und Ziele der Praktiker*innen ein, sondern auch deren Normen und Werte. Die idealtypische transdisziplinäre Forschung geht über rein beratende Forschungsansätze hinaus und ist von dem zu unterscheiden, was als angewandte Forschung konzeptualisiert wird.

Die Regressionsanalyse von 81 Forschungsprojekten und statistische Gruppenvergleiche der fünf Forschungsmodus-Cluster zeigen, dass die gesellschaftlichen und akademischen Ergebnisse und Wirkungen je nach spezifischen Projektmerkmalen und Kombinationen von Projektmerkmalen, definiert als Forschungsmodi, variieren. Die Ergebnisse deuten darauf hin, dass interaktivere Forschungsmodi eine größere gesellschaftliche Wirkung erzielen. Insbesondere die Einbeziehung von Praktiker*innen in frühen Projektphasen und die gezielte Verbreitung der Forschungsergebnisse wirken sich positiv auf die gesellschaftlichen Wirkungen aus. Dieser Befund deckt sich auch mit den Erwartungen der Praktiker*innen an integrative Forschung und Forschungsnutzung, die sich aus der qualitativen Analyse ergeben. Darüber hinaus zeigen die quantitativen Ergebnisse, dass die wissenschaftlichen Ergebnisse und Wirkungen mit der Intensität der Interaktionen abnehmen, was auf einen Zielkonflikt zwischen gesellschaftlichen und wissenschaftlichen Ergebnissen und Wirkungen hindeutet.

Insgesamt unterstützen die empirischen Ergebnisse dieser Arbeit die erwartete Wirksamkeit transdisziplinärer Forschung bei der Bereitstellung von gesellschaftlich relevantem, anwendbarem Wissen und ermutigen zur weiteren Finanzierung transdisziplinärer Forschung durch Förderorganisationen. Die in dieser Studie entdeckten Zusammenhänge zwischen den Merkmalen des Forschungsmodus und den gesellschaftlichen sowie akademischen Ergebnissen und Auswirkungen können Forscher*innen bei der Gestaltung und Reflexion ihrer Forschung helfen und Förderorganisationen bei der Ausarbeitung von Ausschreibungen und Forschungsprogrammen unterstützen. Die beobachteten geringeren akademischen Ergebnisse und Auswirkungen integrativerer Forschungsmethoden werfen jedoch die Frage auf, wie die systematische Dokumentation und Zugänglichkeit der Ergebnisse transdisziplinärer Nachhaltigkeitsforschung weiter verbessert werden können. Der beobachtete Zielkonflikt zwischen den gesellschaftlichen und akademischen Auswirkungen transdisziplinärer Forschung verdeutlicht zudem die Notwendigkeit von Strategien, um den beiden Ansprüchen der transdisziplinären Forschung, zur Lösung gesellschaftlicher Probleme beizutragen, und gleichzeitig wissenschaftliches Wissen zu produzieren zu vermitteln.

Schlagworte: Transdisziplinarität, Nachhaltigkeitswissenschaft, transdisziplinäre Forschung, gesellschaftliche Auswirkungen, wissenschaftliche Auswirkungen, Forschungsmodus, Forschungsbewertung

1 Introduction

"We are living in the midst of this rapid and deep transition, so we cannot predict its outcome. But we can help to create the conditions and the intellectual tools whereby the process of change can be managed for the best benefit of the global environment and humanity." (Funtowicz and Ravetz 1993:754)

Today's societies face multiple and interrelated crises, such as accelerating climate change (IPCC, 2022), rapid biodiversity loss (IPBES, 2019), and ongoing resource depletion (IRP, 2019) that threaten the security and well-being of current and future generations. These crises are characterized by complex and dynamic problem structures that often combine societal and environmental challenges, where much is at stake and solutions are urgently needed (Funtowicz and Ravetz 1993; Jerneck et al. 2011; Kates et al. 2001).

Among many other societal responses to these leading challenges, sustainability science emerged as a new field of research with the aim of "understand[ing] the fundamental character of interactions between nature and society" (Kates et al. 2001:641) and "creating and applying knowledge in support of decision making for sustainable development" (Clark and Dickson 2003:8059). Pursuing these goals, sustainability science is defined by its problem orientation, integrative perspective and application orientation rather than by specific research subjects and a common methodology (Spangenberg 2011; Von Wehrden et al. 2017).

However, the conduct of sustainability science requires a broad range of knowledge and skills that transcend traditional boundaries between academic disciplines and require a direct interface between research and the societal context of application (Jerneck et al. 2011; Kates et al. 2001; Leach, Scoones, and Stirling 2010; Nowotny, Scott, and Gibbons 2001; Spangenberg 2011). Sustainability science is thus strongly linked to the so called "new modes of knowledge production" (Becker et al. 2001; Lang et al. 2012; Scholz et al. 2006) which firm under the labels of "Mode 2" (Gibbons et al. 1994; Nowotny et al. 2001), "post-normal" science (Funtowicz and Ravetz 1993) or transdisciplinarity[1] (Jantsch 1970; Klein et al. 2001).

The core characteristics of transdisciplinary research entail that research activities are based on real-world problems, in distinction to purely inner-scientific questions of basic research (Klein

[1] While transdisciplinary research is strongly connected to sustainability science, it is also discussed and implemented in other applied fields like health research (Sell et al. 2022; Stokols et al. 2008) and the study of social work (Clark, Handlovsky, and Sinclair 2015).

2004; Scholz and Steiner 2015b). It is conducted in collaboration between scholars from different disciplines and practitioners from different sectors of society, such as the private, government, and civil sector (Bergmann et al. 2012; Hirsch Hadorn et al. 2008; Jahn 2008; Scholz and Steiner 2015a). The central underlying assumption is that through these interactions between science[2] and society transdisciplinary research goes beyond the production of knowledge in the form of an in-depth analysis of the problem under study, but provides concrete solutions to the practical problems at hand (Jahn 2008; Lang et al. 2012; Miller et al. 2014).

The body of literature on transdisciplinary research is growing rapidly (Lam et al. 2021; Lawrence et al. 2022; Pohl, Truffer, and Hirsch Hadorn 2017) and the approach itself is widely used[3] (Brandt et al. 2013; Chambers et al. 2021; Pärli, Fischer, and Lieberherr 2022; Zscheischler and Rogga 2015). However, there still remains a gap between theoretical ideal-typical models of transdisciplinary research and the variety of real applications of interactive and integrative research modes within sustainability science (Binder, Absenger-Helmli, and Schilling 2015; Keitsch and Vermeulen 2021; Sakao and Brambila-Macias 2018). And although the study and evaluation of transdisciplinary research and its outcomes has seen much progress in the last years (Belcher et al. 2016; Knickel et al. 2019; Lux et al. 2019), still a rather small proportion of that research uses large-N quantitative comparative approaches (for exceptions see: Binder et al. 2020; Chambers et al. 2021; Hegger and Dieperink 2015; Jacobi et al. 2022; De Jong, Wardenaar, and Horlings 2016; Pärli et al. 2022; Phillipson et al. 2012). Furthermore, while there is a general agreement in empirical studies that transdisciplinary research is societally impactful (Binder et al. 2020; De Jong et al. 2016; Lux et al. 2019; Schneider et al. 2019), there is dispersed and partly contradicting evidence on which of the diverse aspects of transdisciplinary research essentially foster societal impact (Binder et al. 2020; Hegger and Dieperink 2015; Jacobi et al. 2022; De Jong et al. 2016; Pärli et al. 2022). While much work focuses on capturing and describing societal impact, the extent to which transdisciplinarity contributes to scientific progress is still neglected (Hegger and Dieperink 2015; Lam et al. 2021; Lux et al. 2019). Besides, while transdisciplinary research itself is fundamentally based on collaboration with heterogenous societal actors, the research on transdisciplinary research is pretty much dominated by the researcher perspective and the views, experiences and assessments of

[2] In this work ‘science’ is referred to in the holistic notion of the German term “Wissenschaft” following Weingart (2010), as opposed to the distinction between ‘science’ and the ‘humanities’ in the Anglo-Saxon context.

[3] In Germany, where the data for this dissertation were collected, transdisciplinary research projects that aim at fostering sustainability have been funded by the German Federal Ministry of Education and Research (BMBF) since 2000 (BMBF 2015; Bührer et al. 2020).

practitioners are only rarely taken into account (for exceptions see: Binder et al. 2020; Steger et al. 2021; Zscheischler and Rogga 2015).

Responding to these overarching research gaps, the core aim of this doctoral work is to contribute to a better understanding of the actual implementation of transdisciplinary research in sustainability science. By systematically analyzing a larger number of research projects, this thesis identifies and examines the determinants that shape the contribution of transdisciplinary research to the solution of sustainability problems and to scientific knowledge production.

Specifically, this thesis will pursue the following three research aims:

Aim#1 Measurability – Extending the measurability of transdisciplinary research: To contribute to the measurability of transdisciplinary research practices and their societal as well as academic outcomes in a systematic comparative manner by translating concepts from the theoretical literature into observable indicators suitable for different types of research projects.

Aim#2 Demarcation – Demarcating transdisciplinary research in sustainability science: To contribute to a better understanding of what transdisciplinary research is in distinction to other research modes, by challenging theoretical concepts with empirical observations.

Aim#3 Assessment – Linking research modes and impacts: To provide empirical insights for a better understanding of which of the specific characteristics of transdisciplinary research contribute to both societal problem solving and scientific knowledge generation.

This thesis is structured as follows: Section 2 provides the theoretical background of this thesis and Section 3 describes the mixed-methods research design chosen for this work. Section 4 to 6 present and summarize the overarching findings of the three constituting articles along the three research aims defined above. In Section 7 the results are synthesized and discussed with respect to overarching challenges of transdisciplinary research in sustainability science. Section 8 concludes with overarching implications of this thesis for the future study and application of transdisciplinary research.

2 Theoretical background

2.1 Transdisciplinarity and transdisciplinary research

The term transdisciplinarity was first coined by Jantsch (1970), introducing it as a theoretical approach to “facilitate communication among basic sciences, applied sciences and decision making” (Klein 1990:69). Reflecting on the role of science in society, Jantsch (1970) envisioned a science at the “service of society” for a “human purpose” (ibid, p. 412) and emphasized – consistent with the later work of Weinberg (1972) – that many societal problems transcend the boundaries of scientific disciplines. Through increasing disciplinary specialization, the objects of research had become ever-stronger decoupled, research problems had increasingly arisen within science itself, and communication about research had become more and more self-referential (Weingart 2010). This inner-academic "puzzle solving" (Kuhn 2012:35) that distanced itself from societal problem contexts was observed and described in detail by Kuhn (ibid.) as 'normal science'. Transdisciplinarity can hence be perceived as a critique and a progression of ‘normal science’ (Klein 1990; Mittelstraß 1992; Weingart 2010).

Gibbons, Nowotny, and their collaborators elaborated on these ideas, explaining that in modern societies knowledge “is created in broader, transdisciplinary social and economic contexts” (Gibbons et al. 1994:1). In the risk society and knowledge economy, more societal stakeholders expect science to deliver knowledge that is societally beneficial and responding to current public needs (Nowotny 2003; Nowotny et al. 2001). At the same time, educational expansion leads to increasing professionalization of many societal fields and to more certified and uncertified expertise in society, enabling new, participatory modes of knowledge production (Nowotny et al. 2001). Hence, – in distinction from traditional forms of scientific knowledge production – which they define as ‘Mode 1’– ‘Mode 2 knowledge production’ as they call it, is taking place in mutual exchange with the societal ‘context’ of research. Moreover, the whole knowledge production process is shaped by social responsibility. The research activities lead to ‘socially robust knowledge’ which is envisioned to be receivable in different societal contexts – not exclusively within academia (Gibbons et al. 1994; Nowotny 1999a).

In parallel, a very similar argument was developed by Funtowicz and Ravetz (1993): They describe the emergence of ‘post-normal science’ as a type of science that is required in situations of uncertainty, risk and high decision stakes. In this, they distinguish ‘post-normal science’ from ‘core science’, ‘applied science’ or ‘professional consultancy’ by describing it as an interactive dialogue, linking hard facts and analytical rigor with participation and public values (ibid.).

From the first Transdisciplinarity Conference in 2000 in Zürich a discourse and corresponding community emerged that is concerned with translating the theoretical ideas and principles of transdisciplinarity described above into applicable research processes and practices, and with continuously developing these (Klein 2004). Building on this discourse[4], this thesis is strongly influenced by the seminal ideal-typical model of transdisciplinary research by Jahn (2008). This phase model aligns with other (phase) models of transdisciplinary research (Jahn, Bergmann, and Keil 2012; Lang et al. 2012; Lawrence et al. 2022) and was widely applied to various research problems (e.g. Barnett et al. 2022; Brink et al. 2018; Ifejika Speranza et al. 2022; Schaltegger, Beckmann, and Hansen 2013).

In the ideal-typical model, transdisciplinary research "initiates from societally relevant problems that imply and trigger scientific research questions" (Lang et al. 2012:27), which is often referred to as 'real-world orientation' (Klein et al. 2001; Scholz and Steiner 2015b). The research process is conceptualized as two pathways, one pathway to solve the societal problem, flanked by a scientific pathway that delivers interdisciplinary insights, and innovative methods (Jahn 2008). To relate these two pathways, transdisciplinary research is conceptualized as a shared process in three phases: In the first phase, the research problem is framed and formulated jointly by science and practice, by linking societal and scientific problems and questions. In the second phase, "solution-oriented transferable knowledge" (Lang et al. 2012:28) is jointly produced by societal actors and researchers from different disciplines and institutions (Jahn 2008). In the last phase, the co-created knowledge is brought back to and applied in the respective societal and scientific contexts (ibid.). In this regard, transdisciplinary research is closely linked to research uptake and knowledge utilization in the practice field (Hoffmann, Klein, and Pohl 2019; Lux et al. 2019; Miller et al. 2014).

This thesis elaborates in larger parts on the core underlying assumption of transdisciplinary research, that the type, structure and intensity of the interactions shape the outputs and impacts of the research projects (Becker and Jahn 2006; Schäfer, Lux, and Bergmann 2020; Spaapen and van Drooge 2011). While the ideal-typical model defines the core process, the concrete interactions that take place within the model phases can vary: For example, the practice

[4] This thesis does not refer to the discourse shaped by Max-Neef (2005) and Nicolescu (2014) in which transdisciplinarity is envisioned as an approach to science that surpasses disciplines and applies a common, unified logic and language in approximation of the unity of science.

interactions can range from selective, short-term knowledge exchange to strong involvement at various stages of the research process (Stauffacher et al. 2008). Moreover, the practitioners can contribute differently to the research project, in form of knowledge contributions (Bunders et al. 2010; Enengel et al. 2012), by stating their aims, norms and values (Isgren, Jerneck, and O'Byrne 2017; Nowotny 1999b), or by providing material, financial or spatial resources (Spaapen and van Drooge 2011). Besides, the practitioners can have different degrees of influence on the research process and project decisions (Bunders et al. 2010; Fritz and Binder 2020; Fritz and Meinherz 2020). Because of this variability in the manifestations of transdisciplinary process features, the term "research mode" will be used in the following to refer to particular combinations of characteristics of the research process. While this thesis focuses on overarching process features, it is worth noting that transdisciplinary research consists of various and detailed processes of knowledge integration on a smaller scale (Bergmann et al. 2012; Defila and Di Giulio 2015; Hoffmann, Pohl, and Hering 2017; Pohl et al. 2021). These detailed processes can take place more or less formalized and the application of 'methods of knowledge integration' as structured and guided practices are proposed to foster mutual-learning and co-production (Bergmann et al. 2012; Hoffmann et al. 2017).

Transdisciplinary research is associated with a variety of societal impacts, such as increasing awareness of the issue at hand or changing attitudes about the problem and the actions that are necessary to address it (ESF 2012; Walter et al. 2007). Moreover, it is discussed as a deliberative space where different aims and opinions can lead to shared understandings (Bunders et al. 2010; Osborne 2015; Scholz and Steiner 2015a). Transdisciplinary research processes are assumed to provoke (mutual-)learning in the involved actors, leading to altered knowledge, enhanced capacities and the formation of new actor networks (ESF 2012; Schäfer, Bergmann, and Theiler 2021; Walter et al. 2007; Wiek et al. 2014). Further related impacts mentioned are the implementation of the research results in the practice field as well as the actual use of developed products (ESF 2012; Mitchell, Cordell, and Fam 2015). Overall , it is envisioned that transdisciplinary processes lead to a change of individual or organizational practices or directly affect political decisions and policy making (Lam et al. 2021; Walter et al. 2007), improving the problem situation that initiated the transdisciplinary research endeavor (Mitchell et al. 2015).

While it is assumed that the impact of transdisciplinary research on society is exclusively positive, assumptions about the impact on scientific practices and outcomes are more nuanced: On the one hand, it is assumed that transdisciplinary research can lead to less scientific publication output and less citations as the research approach is labor-intense and leaves less room for academic writing which might make it hard to place transdisciplinary papers in high rank journals (Kueffer et al. 2007). On the other hand, it is expected that transdisciplinary research impacts positively on scientific practices and outputs: It may lead to more reflexivity among researchers and to more relevant research results that will also find strong resonance in academia (Hegger and Dieperink 2015). Moreover, transdisciplinary research is supposed to lead to methodological advances and innovative new research questions (Jahn et al. 2012; Lam et al. 2021). It might also lead to new networks in academia and beyond and thus to enhanced career opportunities within or beyond academia and more options for follow-up projects (Hegger and Dieperink 2015).

Finally, transdisciplinary research is context specific and embedded in a particular local environment and field of actors at a particular point in time (Nowotny et al. 2001; Scholz and Tietje 2002). Hence, it must be assumed that the research processes as well as the societal and academic outputs and impacts are shaped by contexts factors, like the funding context, the institutional research and practice surroundings, as well as the specific sustainability problem setting (Hall et al. 2012; Scholz et al. 2006; Wamsler 2017).

2.2 Adjoining concepts and discourses

There are two prominent adjacent discourses in the field of integrative research that partly overlap with the discourse on transdisciplinary research: the discourses on 'co-production' and 'participatory (action) research'.

The concept of 'co-production' originates from Ostrom (1996), who described the provision of public services as a collaborative effort of the whole society, not only offered by the government (Norström et al. 2020). It was adapted as 'knowledge co-production' by sustainability research and encompasses the ideas of Mode 2 science, post-normal science, participatory action research, further collaborative research forms, and also transdisciplinary research (Chambers et al. 2021; Norström et al. 2020). Hence, 'knowledge co-production' serves as an umbrella concept for all types of complex collaborative research that involves diverse societal actors from outside academia as partners in the production of knowledge with the aim of addressing complex sustainability challenges (Chambers et al. 2021; Djenontin and Meadow 2018; Lawrence et al. 2022). As such, the concept is open and inclusive to a great variety of approaches, but also remains ambiguous in its meaning and application (Chambers et al. 2021).

The other discourse around ‘participatory (action) research’ originates from research initiatives with oppressed groups in the global south (Brown and Tandon 1983; Freire 1974). It encompasses a set of “research designs, methods, and frameworks that use systematic inquiry in direct collaboration with those affected by the issue being studied for the purpose of action or change” (Vaughn and Jacquez 2020:1). Participatory research strongly concurs with the basic ideas of transdisciplinary research as it “engages community stakeholders in the research process, from problem identification and developing the research question, to dissemination of the results” (Duea et al. 2022:549). However, the concept of ‘participatory research’ tended to co-evolve with transdisciplinary research, and the discourses still seem only loosely connected (Vaughn and Jacquez 2020). Currently, ‘participatory research’ is predominantly – but not exclusively – discussed and implemented in health research (Duea et al. 2022; Tebes and Thai 2018; Vaughn and Jacquez 2020).

Further to mention are two more specific research formats that were established in recent years that adjoin to the concept of transdisciplinary research: ‘citizen science’ and ‘real-world laboratories’.

Citizen science is an approach in which citizens are primarily involved by collecting and classifying data (Kullenberg and Kasperowski 2016). Beyond that, citizen science projects apply “diverse approaches to co-design, co-production and co-dissemination” that relate to transdisciplinary practices (Pettibone et al. 2018:222). Citizen science can enhance public understanding of science and support, or flank participatory political processes that are related to the topic of the data collection (Dickinson et al. 2012; Gura 2013).

In the last years, real-world laboratories gained momentum as a new form of transformative research (Rogga, Zscheischler, and Gaasch 2018; Schäpke, Bergmann, et al. 2018). Real-world laboratories combine the general principles of transdisciplinary research with experiments as core research method (Bergmann et al. 2021; Schäpke, Stelzer, et al. 2018). These experiments are centered around a real-world intervention (Caniglia et al. 2017) with the aim to “generate evidence related to action fostering sustainability transformations” (Schäpke, Bergmann, et al. 2018:87).

While this thesis does not explicitly refer to these discourses and adjoining approaches, the considerations and results of this work can partly be interpreted in their context as the concepts share the basic ideas of transdisciplinary research as defined above and partly entail the concept itself.

3 Methodology

3.1 Epistemological foundation

All work of this dissertation project is based upon the epistemological paradigm of critical rationalism as promoted by Popper (2005): Accordingly, I am convinced that personal values and subjective assumptions of the single researcher can never be fully eliminated or separated from the scientific work. But I believe in the effectiveness of the critical method that is proposed by Popper: By open and critical discussion of the research approaches and results by different scholars within the scientific community – over time – individual values and presumptions can be minimized in approximation of objectivity (ibid.). This epistemological paradigm has led to the following actions in the realm of this dissertation project:

Much effort was put into the permeation of the previous scientific discourse on transdisciplinarity in sustainability science to acknowledge and value the already achieved collective standpoints and to build upon them. Thorough and careful application of established scientific methods and detailed and transparent reporting of these took place to make research most accessible for the critical peer group. Furthermore, previous stages and parts of this work have been exposed to critical discussion at conferences, colloquia and in workshops with the scientific advisory board of the research project "Modes of sustainability related research in comparison (MONA)" in the context of which bigger parts of this thesis took place. Finally, all publications that form the core of this work have been published in high-quality peer reviewed journals.

3.2 Context

The empirical work of the three publications that form the basis of this thesis was conducted in the context of two research projects: The project "Modes of sustainability related research in comparison (MONA)" founded by the German Research Foundation (DFG) and the project "ALTERFOR – Alternative models for future forest management" that was founded by the European Union Horizon 2020 research and innovation program. Both projects strongly shaped the conceptual and methodological approaches of the resulting papers.

The core contributions of this dissertation (Article 1 [A1] and Article 2 [A2]) result from the research project MONA – in particular the MONA large-N study. The aim of the MONA large-N study was to provide an extensive dataset for a systematic comparison of a larger number of research projects, and to link specific characteristics of more or less transdisciplinary research modes with societal and scientific outputs and impacts. Guided by 14 hypotheses, data were collected using a modification of the Case Survey Method (Newig and Fritsch 2009; Yin and Heald 1975). The Case Survey Method is a non-reactive, ex-post approach for the meta-analysis of a larger number of case studies (Yin and Heald 1975). In the MONA project it was adapted to analyze and compare research process characteristics of a larger number of projects as well as their general outputs and impacts, rather than their specific content-related results. The analysis was guided by a coding scheme with the aim to transform predominantly qualitative information into quantitative measures and to hence make previously qualitative information accessible for formal analyses (Bullock & Tubbs, 1987 via Newig & Fritsch, 2009). Sources were all relevant and available documents and information on one project (Newig and Fritsch 2009), like research proposals, project reports, publications, content from webpages, print and online reports. For reasons of data availability, the coding scheme was supplemented with a questionnaire addressed to the principal investigator of the project. The resulting data were analyzed using established statistical procedures for all 81 projects [A2] and for a subset of 59 projects for [A1]. The quantitative large-N sub-study was paralleled by the qualitative MONA in-depth sub-study that investigated a subsample of six projects of the large-N study.

Article 3 [A3] of this thesis is based on the Bavarian case study of the international ATERFOR project. The focus of interest of this paper is explorative and the applied methods are of a qualitative nature. [A3] additionally provides a conceptual comparison of three modes of knowledge production and research utilization based on a narrative literature review. All empirical data for this thesis rely on research projects in a German research context.

The individual methodological approaches that are used in [A1] to [A3] are described in detail in the respective articles and summarized for an overview in Table 1.

This cumulative dissertation consists of the following three publications:

Article 1 [A1]: **Jahn, Stephanie**, Jens Newig, Daniel J. Lang, Judith Kahle, and Matthias Bergmann. 2022. Demarcating transdisciplinary research in sustainability science – Five clusters of research modes based on evidence from 59 research projects. *Sustainable Development*, 30(2), 343-357.

Article 2 [A2]: Newig, Jens, **Stephanie Jahn**, Daniel J. Lang, Judith Kahle, and Matthias Bergmann. 2019. Linking modes of research to their scientific and societal outcomes. Evidence from 81 sustainability-oriented research projects. *Environmental Science and Policy* 101, 147-155.

Article 3 [A3]: Juerges, Nataly and **Stephanie Jahn**. 2020. German forest management stakeholders at the science-society interface: Their views on problem definition, knowledge production and research utilization. *Forest Policy and Economics* 111, 102076.

Table 1: Overview over the articles and their research approaches

	Article 1 [A1]	**Article 2 [A2]**	**Article 3 [A3]**
Short title	Jahn et al. 2022 Demarcating transdisciplinary research	Newig et al. 2019 Linking modes and impacts	Juerges & Jahn 2020 Stakeholder views
Project	MONA – Modes of sustainability related research in comparison (German research foundation, DFG) Large-N study	MONA – Modes of sustainability related research in comparison (German research foundation, DFG) Large-N and in-depth study	ALTERFOR – Alternative models for future forest management (European Union Horizon 2020 research and innovation program) Bavarian case study
Unit of analysis	Research project	Research project	Individual stakeholder
Population (N)	156 interdisciplinary sustainability-oriented research projects with social science share, conducted between 2000 and 2012, funded by the DFG or the BMBF	156 interdisciplinary sustainability-oriented research projects with social science share, conducted between 2000 and 2012, funded by the DFG or the BMBF	Stakeholders with different interests in forest ecosystems in the district of Augsburg (Bavaria)
Number of observations (n)	59	81	21
Representativeness of sample	Full survey of the population, 38 % of the projects provided sufficient data for the analysis. No significant differences compared to the population in terms of funding sum, funding duration and affiliation of projects to the two funding agencies and the respective funding lines within the funding agencies	Full survey of the population, 52 % of the projects provided sufficient data for the analysis. No significant differences compared to the population in terms of funding sum, funding duration and affiliation of projects to the two funding agencies. Overrepresentation of projects from the funding line 'WIN' within the projects funded by the BMBF	Interviewee selection based on stakeholder analysis
Design	Quantitative ex-post evaluation	Quantitative ex-post evaluation	Qualitative cross-sectional study
Data analysis	Cluster analysis, test statistics	Linear regression analysis, qualitative content analysis	Narrative literature review, qualitative content analysis
Data collection	2014 - 2019	2014 - 2019	2016
Contributions to aims	Aim 1- Aim 3	Aim 1 & Aim 3	Aim 2 & Aim 3
Conceptual or empirical contribution	Conceptual & empirical	Empirical	Conceptual & empirical

3.3 Research design

The overall research design of this dissertation follows a mixed-methods design, combining a strong quantitative component with selected in-depth qualitative inquiries (Johnson, Onwuegbuzie, and Turner 2007). The quantitative parts build the center of the dissertation project, providing data from a larger number of research projects to offer more external validity and generalizability (ibid.) than the small-n case studies that previously dominated the field (as described in Section 1 Introduction). Qualitative methods and the subsequent results are used to support, enrich or contrast the quantitative parts of this work (Rossman and Wilson 1985) to balance the methods strengths and biases (Greene, Caracelli, and Graham 1989). In the following, the entanglement of quantitative and qualitative data in this dissertation project is described along the five purposes for mixed-methods research as identified by Greene et al. (1989): expansion, development, complementarity, triangulation and initiation.

Overall, this dissertation project uses different methodological approaches for different components of the inquiry in order to "to expand the breadth and range of inquiry" *(expansion)* (Greene et al. 1989:259): While [A1] focuses on large-N quantitative research to find structure in data, [A2] combines a large-N quantitative approach to discover generalizable relationships between research project characteristics, outputs and impacts with a qualitative analysis that focuses on the underlying mechanisms of these relationships. In addition, in order to explore the various experiences and opinions of stakeholders in a research setting at the science-society interface, [A3] is based on a qualitative research design.

To serve Aim #1 Measurability, the mixed-method process of using "results from one method to help develop or inform the other method" (*development)* (Greene et al. 1989:259) was applied: A part of the data that was collected for [A1] and [A2] was initially gathered as open, unstructured text material. Via a systematic content analysis, this open material was structured and transformed into quantitative items, which were then used to code the same open material transforming qualitative information into quantitative data points (Onwuegbuzie, Bustamante, and Nelson 2010).

Central to this work is also the combination of the results of the qualitative and quantitative methods on the same assumptions and datasets to illustrate and elaborate on the results of each method (*complementarity)* (Greene et al. 1989; Rossman and Wilson 1985): In keeping with Aim #2 Demarcation, short case descriptions of the most representative cases for the different clusters were used in [A1] to exemplify and to increase the interpretability of the quantitative results. The same holds true for [A2], which supports Aim #3 Assessment as the results of the qualitative MONA in-depth study illustrate, clarify and enrich the quantitative results of the MONA large-N study.

In [A2], the validity of scientific results is enhanced by the synthesis of the MONA large-N sub-study and the qualitative in-depth study to "seek convergence, corroboration, correspondence of results from different methods" (Greene et al. 1989:259) *(triangulation)*.

Last, the confrontation of results from qualitative and quantitative data sources is used in the small sub-discussions of the results on Aim #2 Demarcation (Section 5) and Aim #3 Assessment (Section 6) and the overall Discussion and Conclusion (Sections 7 and 8) to enable the discovery of paradoxes and contradictions and to formulate new research questions and ideas for future investigation (*initiation*) (Greene et al. 1989; Johnson et al. 2007; Rossman and Wilson 1985).

Overall, this thesis is emphasizing empirical over theoretical contributions and establishes a specific relationship between theoretical and empirical work: Initial conceptual clarification is achieved by translating theoretical conceptualizations of transdisciplinary research from the literature into a set of tangible indicators (Aim #1, Section 4). Building on this, an exploratory statistical approach, cluster analysis, is used to expand the conceptual understanding of transdisciplinary research based on the structures identified in empirical data (Aim #2, Section 5.1).

4 Results for Aim #1 Extending the measurability of transdisciplinary research

4.1 *Challenge*

Measuring and evaluating transdisciplinary research is challenging because it is a complex and context-dependent research approach that is applied to a variety of different problems within sustainability science with various outcomes (Belcher et al. 2016; Jahn and Keil 2015; Lawrence et al. 2022). Classic research evaluation assesses scientific excellence mainly through scientific outcomes like academic publications and their citation (Belcher et al. 2016; DFG 2022). In distinction to this, previous works that examine and evaluate transdisciplinary research predominantly developed indicators that capture the research process and the social outputs and impacts (e.g. Binder et al. 2020; Jacobi et al. 2022; Knickel et al. 2019). Still missing is an indicator set with an integrated perspective that covers different degrees and modes of transdisciplinarity, looks at both societal and scientific outputs and impacts and also considers context factors (Lam et al. 2021; Lang et al. 2012; Lawrence et al. 2022).

In addition, so far only a small proportion of works used quantitative approaches to compare and analyze a larger number of transdisciplinary research projects (for exceptions see e.g. Binder et al. 2020; Hegger and Dieperink 2015; Jacobi et al. 2022; De Jong et al. 2016; Pärli et al. 2022; Phillipson et al. 2012). However, it has been shown that structured, comparative studies in particular provide meaningful empirical evidence for the respective object of study, as they are based on a larger number of case-related data (see e.g. Newig and Fritsch 2009).

The application of a deductive, quantitative approach needs to be built upon a profound research design and well-defined variables (Angrist and Pischke 2009). As a first result, this Section describes the contribution of this work to the measurability of inter- and transdisciplinary research, its social and scientific outcomes and impacts, and its context with a structured, quantitative approach. The Section provides further background on the operationalization logic and process and relates the efforts of this dissertation to other operationalization efforts in the field.

4.2 Measuring process, impact and context characteristics of transdisciplinary sustainability research

While also other research in the field performed systematic document analysis combined with complementary surveys (e.g. Bührer et al. 2020; De Jong et al. 2016), in [A1] and [A2] of this thesis the logic of the 'Case Survey Method' (Yin 2009; Yin and Heald 1975) (see Section 3.2 Context) was adapted and applied for the first time as an overarching heuristic to develop items to measure process characteristics, outcomes and the context of transdisciplinary sustainability research. Based on a narrative literature review[5] departing from the review article of Lang et al. (2012), theoretical concepts that describe inter- and transdisciplinary sustainability research were translated into an extensive set of precise, observable variables[6] (Christophersen and Grape 2009). Depending on data availability, these items were split between a coding scheme

[5] Transdisciplinary research as a structured scientific practice is outlined in a set of handbooks, guidelines, and compilations of quality criteria (Belcher et al. 2016; Bergmann et al. 2005; Defila, Di Giulio, and Scheuermann 2006; Hirsch Hadorn et al. 2008; Knickel et al. 2019; Lang et al. 2012), which the operationalization of transdisciplinary research in this thesis strongly builds upon.

[6] In order to link theoretical concepts with empirical observations, the difficulty lies in defining items that either capture observable aspects of theoretical concepts fully in their sum (dimensions) or define an observation that represents the concept (indicator) (Christophersen and Grape 2009).

for document analysis and a questionnaire to the research project leader with the goal to collect as much data as possible through document analysis[7].

The resulting indicator set provides an integrative perspective on transdisciplinary research (Lam et al. 2021), covering the research mode, societal and academic outputs and impacts and the research context (for an overview of the indicators please see supplementary online material of Article 1 [A1_OSM]). The research mode is represented by indicators for specific research process characteristics that allow not only to capture different degrees of (transdisciplinary) interaction, but can represent in their specific combination specific modes of research, as they encompass the following dimensions: a.) the real-world orientation, as the degree to which the project was oriented towards societal problems in comparison to inner-scientific questions, b.) the intensity and frequency of interactions with practitioners, and c.) the type of contributions of non-academic actors, for example to the formulation of the research question or to the assessment of the research results.

The indicator set also entails items that cover both societal outputs and impacts (for more detail see Section 4.3) as well as academic outputs and impacts. It was the explicit aim of this work to link inter- and transdisciplinary research process characteristics to classical scientometric indicators like academic publications and their citations to analyze the performance of research projects. Especially, as these indicators are still central to funding decisions and scientific careers (DFG 2022). Although the scientometric approach that was applied for this work is very labor-intensive[8], it provides in comparison with Hegger and Diperink (2015) concrete numbers of publications and citations rather than estimates of the interviewees and a more precise attributability of publications to the research project than the work of Bührer et al. (Bührer et al. 2020). Finally, the indicator set is complemented with variables on the research context which encompass the funding context, inter-academic collaborations, and the spatial scale to which the question of the project referred to.

---

[7] While the original goal was to gain as much information as possible by coding all available research documents, the pretest of the coding scheme showed that the standard documentation of most interdisciplinary and transdisciplinary research projects was not sufficient to answer the research questions posed. Many projects for example did neither report on forms and intensity of practitioner interactions, nor on societal outcomes and further societal impacts. Thus, several items were moved to a complementary questionnaire to the principal investigator – giving up on a predominantly non-reactive approach while still staying with the logic of using all available data material for one case.

[8] To measure scientific performance in this dissertation, a list of academic project publications, presentations and events from webpages and project documents was compiled. Then this list was reviewed and supplemented by the principal investigator of the project. In the next step, each publication was searched in Google Scholar and the citations within the five years after publication were documented (for a detailed description, please see the online supplementary material of Article 1 [A1_OSM]).

In previous research, most indicators for capturing transdisciplinary research were developed primarily for evaluation or self-reflection purposes (e.g. Belcher et al., 2016; Bergmann et al., 2005; Knickel, Knickel, Galli, Maye, & Wiskerke, 2019). The items developed in this dissertation primarily serve an analytical aim: to discover relationships between research mode characteristics, project outputs and impacts and the project context. For this reason, the set of items encompasses no evaluative questions that rely on expert judgement. The coding scheme and questionnaire apply a retrospective perspective and capture whether the research projects displayed specific characteristics and what concrete outputs and impacts of the projects were observed. This allows data to be collected on very different projects and allows for intersubjective comprehensibility. Although the indicators used in this work serve an analytical aim, they also allow for relative comparisons of different projects which can additionally be interpreted from an evaluative perspective.

4.3 Four complementary scales to measure the societal impacts of research

Although a variety of investigations on the societal impacts of transdisciplinary research have been conducted in recent years (e.g. Belcher, Ramirez, et al. 2019; Fritz et al. 2019; Lux et al. 2019; Schneider et al. 2019), these "are characterized by inconsistent definitions regarding the scope and different forms of effects" (Schäfer et al. 2021:1). Like the work of Schäfer et al. (2021), Schneider et al. (2019) and Fritz et al. (Fritz et al. 2019), the impact scales presented in this dissertation work are based on the empirical foundation of reported societal impacts of actual research projects – in contrast to categories of societal impact that are result of conceptual considerations (e.g. Luederitz et al. 2016; Mitchell, Cordell, and Fam 2015; Williams and Robinson 2020).

The special challenge in the development of a scale to capture societal impact is to develop an instrument that is lean enough to truly allow for a categorization in the sense of a reduction of the complexity of heterogenous real-world observations. Still, it ought to be detailed enough to really comply with the variation in impact between the research projects (Wickson and Carew 2014).

In comparison to this work, the current literature provides on the one hand more broad and overarching concepts and more detailed compilations of different forms of societal impacts on the other hand: For example Fritz et al. (2019) developed the three overarching nested 'arenas' of societal impacts from a qualitative investigation on impact pathways in seven research projects. In contrast to this, the works of Walter et al. (2007), Wiek et al. (2014), Ruppert-Winkel et al. (2015), Williams and Robinson (2020) offer more detailed compilations of various forms of societal impacts in more detail and specificity. Schäfer et al. (2021) offer both, a detailed compilation of various forms of societal impact organized into three all-encompassing "orders" of societal impact derived from the qualitative analysis of 16 transdisciplinary projects.

The impact scales presented in this dissertation work (Graph 1) can be seen as an intermediary link between more overarching, broad impact categories and more detailed lists of different forms of impacts. In the realm of this dissertation work, the qualitative answers of two open questions in the MONA questionnaire[9] were analyzed and structured via a qualitative content analysis (Früh 2017). Four scales were discovered that cover distinct, but complementary dimension of societal impacts (see Table 2): The (a) depth of the impact in the sense of how deep and lasting the project results impact on societal actors and processes, the (b) distribution of the results on a spatial scale as well as (c) into different societal sectors. Last, (d) the scope of the uptake of the project and it´s result by the media. Moreover, the four scales can be integrated as a measure of overall societal impact by using the arithmetic mean of all four impact variables, as applied in [A2].

The other works in the field mentioned above that provide more detailed impact categories propose indicators of societal impact on a nominal scale level, foremost to describe and distinguish societal impacts (Ruppert-Winkel et al. 2015; Walter et al. 2007; Wiek et al. 2014). Other works provide impact scales on an ordinal scale level to get hold of different levels or degrees of societal impacts, like for example Schäfer et al. (2021) and Fritz et al. (2019).

Studies that used interval scaled variables to measure societal impact use rather broad scales like for example Phillipson et al. (2012) who measure “high”, “slight” or “no impact” on practitioner knowledge and practices or Belcher et al. (2016; 2019), who rate various rubric statements on a three point scale. De Jong et al. (2016) rate individual items that show content wise overlaps with the items developed for this work on a Likert scale.

[9] (1) “If your project results were of importance for practitioners or society in general: What are the results and who are the target audience for these results?” [Text field], (2) “Do you know if and how your research results are perceived or implemented by real-world actors and civil society?” [Text field]

Graph 1: Overview over the developed impact scales

(a) Impact_depth

Scale item:	**Qualitative example:**	**Weight:**
Recognition	Civil society actors became aware of the project and asked for the project findings on organic farming networks.	1
Discussion	Project findings on rural development were discussed in municipal council meetings.	2
Test (exemplary use)	Flood protection strategies developed in the project were tested in one federal state.	3
Application (real use)	The practical project results in the form of energy consulting were used by local citizens and copied by another municipality.	4
Continuation (continuous application)	The strategies developed in the project were laid down in intermunicipal agreements on the future use of regional green spaces.	5
Summative index depth of societal impact		

(b) Impact_scale

Scale item:	**Weight:**
Within the project	1
Local	2
Regional	3
National	4
International	5
Summative index of spatial distribution of societal impact	

c) Impact_sector

Scale item:	**Weight:**
Govern-mental sector	1
Private sector	1
Civic sector	1
Citizens	1
Education	1
Media	1
Summative index of the sectoral distribution of societal impact	

d) Impact_media

Scale item:	**Weight:**
Uptake in independent newspapers and magazines, print run	< 100.000 = 1 100.000-200.000 = 2 200.000-300.000=3 300.000-400.000=4 > 400.000=5
Uptake in independent radio reports, outreach	local=1 regional=2 national=3
Uptake in independent TV reports, outreach	local=1 regional=2 national=3
Uptake in practice outlet (mostly webpages and brochures)	1
Summative index of media uptake	

(e) Impact_total: Summative index of all four impact scale indices

However, they use these items that represent very different degrees of depth and range of societal impact in an unweighted index, which limits the interpretability of the index.

The impact scales developed in the realm of this thesis propose ways to acknowledge differences in the degree of the societal impact in four dimensions (see Graph 1). Individually as well as in their combination as a summative index of overall societal impact, they generate values on the interval scale level, allowing for detailed quantitative comparison and further statistical analysis of the relationship between societal impacts and other measured variables. The combination of the four scales provides a wide-ranging perspective on societal impact, covering distinct, but complementary aspects to understand societal impact.

4.4 Summary

This thesis can be seen as a successful adaptation of the Case Survey Method for the systematic, comparative analysis of inter- and transdisciplinary sustainability research and its outputs and impacts. It provides a set of indicators that represent an integrative understanding of transdisciplinary research, encompassing research mode characteristics, societal and academic outputs and impacts of the project as well as the context. The proposed indicators cover a wide range of different projects within sustainability science and transform their experiences into interval-scaled data for advanced statistical analysis. Moreover, the item set offers coding without expert judgement. Additionally, the scales that were developed to capture societal impacts of transdisciplinary research are grounded in empirical observations of real impact descriptions of the research projects and provide a medium level of detail, bridging between other indicators presented in the literature that are either more abstract or more detailed.

5 Results for Aim 2# Demarcating transdisciplinary research in sustainability science

5.1 Challenge

Within the last years, several works became available that provide structured overviews over the key conceptualizations and characteristics of transdisciplinary research (Keitsch and Vermeulen 2021; Klein 2021; Lawrence et al. 2022; Pohl et al. 2021; Renn 2021). While these works integrate and offer guidance in a discourse in which concepts and definitions have long been contested (Belcher et al. 2016; Jahn et al. 2012), they are rather describing what transdisciplinary research is, than delineating it actively from other forms of research or telling what it is not.

At the same time, Norström et al. (2020) and Chambers et al. (2021) for example are even further broadening the concept, subsuming various forms of integrative research under the label of knowledge co-production as a "loosely linked and evolving cluster of approaches, including participatory research, mode 2 science, interactive research, civic science, post-normal science, transdisciplinary and joint knowledge production, action research, translational ecology and engaged scholarship" (Norström et al. 2020:183). Yet, as Jahn et al. (2012:1) argue, "where concepts or ideas are not properly defined the risk is that a rather shallow interpretation prevails" and that the "true challenges of transdisciplinary collaboration are underestimated and that those who take them seriously become marginalized".

Hence the second aim of this dissertation work is to strengthen the conceptual clarification of transdisciplinary sustainability research, by demarcating it from other forms of research, both conceptually and empirically.

This Section will summarize the theoretical demarcation efforts of [A3] in which the underlying rationales of problem definition, knowledge production and research utilization of transdisciplinary research were theoretically delineated from the respective rationales of normal science and political use of scientific knowledge. Moreover, the results of [A1] will be summarized, in which 59 inter- and transdisciplinary research projects within sustainability science were able to be grouped empirically in five distinct research modes through an explorative cluster analysis.

5.2 Theoretical differentiation of normal science, political use of scientific knowledge and transdisciplinary research

[A3] provides a theoretical differentiation of three scientific conceptualizations of the science society interface in the field of forest research with respect to their underlying logics of problem definition, knowledge production and research utilization. Science-society interface is used here as an open concept for contexts in which interactions between scholars and practitioners take place (Fritz 2020). It encompasses research modes like transdisciplinarity, but also less structured processes of knowledge transfer (Guimarães Pereira, Guedes Vaz, and Tognetti 2017).

Through a narrative literature review, three main conceptualizations of science-society interfaces were found that are most actively applied and discussed in forest research: normal science, political use of scientific knowledge and transdisciplinary research (e.g. Beland Lindahl & Westholm, 2014; Böcher & Krott, 2014; Kleinschmit, Böcher, & Giessen, 2009; Pregernig, 2000; Salomaa et al., 2016). To systematically juxtapose the three theoretical conceptualizations, three categories were used that refer to the core processes of transdisciplinary research (Jahn 2008; Lang et al. 2012): Agency of problem definition, agency of knowledge production and use of scientific knowledge (see Table 1 in [A3], p. 4).

[A3] sheds light on *normal science* which is often used as an antitype of integrative research approaches, most prominent in the introduction of post-normal science by Funtowicz and Ravetz (1993) but also underlying the distinction between Mode 1 and Mode 2 research in Gibbons et al. (1994). Yet, the underlying assumptions of normal science about problem definition, knowledge production, and research use remain implicit.

For *normal science*[10] it is assumed that academic actors have the exclusive agency of problem definition as well as knowledge production (Cash et al. 2003; Jasanoff 2003) and that research is "removed from considerations of application" (Grundmann 2009:398). However, there are two related conceptualizations of research utilization: the (a.) 'linear model of knowledge transfer' assumes that research leads to clear and unambiguous information is therefore of general use for society (Beck 2011; Grundmann 2009). Thereby barriers to knowledge uptake by practice are neglected (Böcher and Krott 2014; Jasanoff 2014; Pregernig 2014). Whereas (b.) the 'two communities' thesis assumes that science is separated from other societal systems and their particular logics and communication which fundamentally hinders the transfer of knowledge from science to other parts of society (Cash et al. 2003; Jasanoff 1987; Pregernig 2014).

With respect to the question of the agency of problem definition, the field of *political use of knowledge* distinguishes between research that was produced pursuing inner-academic research questions and research that is conducted in service of specific political actors or institutions (Giessen, Kleinschmit, and Böcher 2009; van Kerkhoff and Lebel 2006). Conceptualizations of *political use of scientific knowledge* assume that knowledge – like in *normal science* – is foremost produced within academia and by academic actors. However, the utilization of the

[10] Funtowicz and Ravetz set normal science equal with "core science – the traditional 'pure' or 'basic' research" (1993:740).

generated knowledge in practice and politics is highlighted and at the same time problematized (Boaz et al. 2019; Maasen and Weingart 2005). Translation processes, intermediary actors and institutions to foster research utilization are conceptualized (Jasanoff 1998; van Kerkhoff and Lebel 2006; Lentsch and Weingart 2011; Pielke Jr 2007; Weingart and Lentsch 2008) and misuse and misinterpretation of scientific knowledge are discussed (Giessen et al. 2009; Grundmann 2009; Lövbrand 2009; Lund, Boon, and Nathan 2009; Ojha, Cameron, and Kumar 2009; Steffek 2009).

As already outlined in Section 2, the concept of *transdisciplinary research* calls for scientists and stakeholders to define research problems and produce knowledge jointly (Gibbons 1999; Jahn 2008; Lang et al. 2012; Nowotny et al. 2001) by actively involving stakeholders from outside academia into research processes at various stages (Stauffacher et al. 2008). The rationale of research utilization behind transdisciplinary research is that intensive involvement of actors from outside academia (for instance practitioners, politicians, business, civil society or NGOs) in research processes will lead to better or more socially robust knowledge (Nowotny 1999b). Therefore, it is more likely that this knowledge will be applied and eventually contribute more directly to solving societal problems (Funtowicz and Ravetz 1993; Lang et al. 2012; Miller et al. 2014; Scholz et al. 2006).

5.3 Empirical demarcation of ideal-typical transdisciplinary research from other modes of research

The five distinct research modes presented in [A1] emerged from a cluster analysis of 59 completed sustainability-oriented research projects and is based on 23 variables representing the three dimensions of an ideal-typical transdisciplinary research process: (a.) real-world orientation, (b.) intensity of interactions with actors from outside academia, and (c.) types of contributions of the involved actors from outside academia (for an overview, see Table 2).

The five identified research mode clusters can be related to existing theoretical conceptualizations and empirical studies[11] that previously structured practices of transdisciplinary research.

[11] Also the works of (Chambers et al. 2021) and (Tribaldos et al. 2020) clustered interactive research projects to discover distinct types, but their clustering variables differ strongly from the ones used in A1, hence the referenceability is limited.

Table 2: Simplified overview over the core characteristics of the five research mode clusters presented in [A1], Table 2, p. 359

Cluster	***Core Characteristics***
Cluster 1 ***Purely academic research*** (n = 6)	- No practitioners actively involved
Cluster 2 ***Practice consultation*** (n = 9)	- Practitioners consult the research project - Main practitioner contribution: provision of knowledge - No application of structured methods of knowledge integration
Cluster 3 ***Selective practitioner involvement*** (n = 19)	- Mainly short-term collaborations with practitioners - Main practitioner contributions: provision of knowledge, assessment of the research results, dissemination of the research results - Low degree of application of methods of knowledge integration
Cluster 4 ***Ideal-typical transdisciplinary research*** (n = 16)	- Mix of short-term and long-term collaborations with practitioners - Practitioners involved in project decisions - Main practitioner contributions: Problem definition, needs & goals, norms & values, assessment, dissemination, implementation - Application of structured methods of knowledge integration
Cluster 5 ***Practice-oriented research*** (n = 9)	- Collaborations with practitioners as equal research partners - Practitioners involved in project decisions - Main practitioner contributions: Research question, needs & goals, product development, financial and material resources, assessment, dissemination, implementation - Low degree of application of methods of knowledge integration

Generally, the research mode cluster structure that emerged from the analysis can be related to Mobjörk's (2010) theoretical distinction between “consulting” and “participatory” transdisciplinarity. The cluster structures main dividing line (Figure 2 in [A1], p. 348) separates Clusters 1–3 from Clusters 4 and 5. Clusters 2 and 3, applying a problem focus, but limited interactions with practitioners by responding and reacting to the research, these two clusters refer to what Mobjörk (ibid.) defines as “consulting” transdisciplinarity, where participation is limited mainly to information inputs from practitioners. Whereas Clusters 4 and 5, in which practitioners are fully included in the knowledge production process can be related to Mobjörk’s (ibid.) concept of “participatory transdisciplinarity” which they define as a research approach with substantial practice involvement and knowledge co-production.

Furthermore, the stronger demarcation between Clusters 2 and 3 and Clusters 4 and 5 align with the two distinct clusters of ‘classical consultative research’ and ‘practical problem-solving and co-innovation’ that Fernández González et al. (2021) found in their cluster analysis of 68 projects described in scientific publications in the field of agroecology.

However, although the projects in Clusters 2 and 3 encompass almost half of the projects in the sample (28 out of 59 projects, 47%), it was not possible to further connect them to more specific theoretical concepts or models of research modes, except for their more overarching consultative manner. Yet, the combination of characteristics of Cluster 4 strongly relates to what has been described as an ideal type process of transdisciplinary research by Jahn (2008), Bergmann (2012) and Lang et al. (2012).

The comparison of Cluster 4 with practice-oriented Cluster 5, [A1] contributes to the conceptual demarcation between transdisciplinary research and what is discussed in the literature under the concept of applied research (Grunwald 2015; Mobjörk 2010; Niiniluoto 1993): It displays the highest scores of practitioner influence, more practitioner contributions to product development and resources and less heterogenous actors involved with an overrepresentation of private actors. This comparison also demarcates the ideal-typical transdisciplinary research cluster (Cluster 4) as a research mode that is not equal to pure practitioner-led research. Based on the specific cluster structure, it is characterized by an intensive, but balanced involvement of practitioners, which incorporates their needs and goals as well as their norms and values (Isgren et al. 2017). Furthermore, it is characterized by an intention to mediate between different actors or actor groups (Scholz and Steiner 2015a) and is supported by the application of structured methods of knowledge integration (Bergmann et al. 2012).

As the projects in Cluster 1 didn´t actively involve practitioners, the only available information on this cluster is that its research questions are slightly drawn towards inner-scientific questions and that it shows a rather low application orientation. Nevertheless, this cluster serves as a reference category for further analysis with output-variables as will be described in Section 6 on Aim 3# Linking modes and impacts.

5.4 Summary

Based on these findings, this thesis contributes to a better delimitability of transdisciplinary research as a research mode within sustainability science. This work strengthens the theoretical understanding of normal science as a counter-concept to transdisciplinary research and conceptually distinguishes the logics of problem definition, knowledge production and research use of normal science, the political use of scientific knowledge, and transdisciplinary research. Moreover, it clarifies based on empirical evidence that ideal-typical transdisciplinary research on the one hand goes beyond less integrative, more consultatory research approaches, but is also not equal to pure practitioner-led research and can therefore be distinguished from what is conceptualized as applied research. Consequently, transdisciplinary research is characterized by an intensive, but balanced involvement of practitioners, supported by the application of structured methods of knowledge integration. Moreover, it incorporates not only the needs and goals of the practitioners but also their norms and values.

6 Results for Aim 3# Linking modes and impacts

6.1 Challenge

The concept of transdisciplinary research in sustainability science is closely linked to the expectation that transdisciplinary research will bring research results more directly into application and thus support sustainability solutions (Becker and Jahn 2006; Hoffmann et al. 2019; Klein 2014; Lang et al. 2012; Scholz and Steiner 2015a). Therefore, many recent works empirically address the impact potentials and impact pathways of transdisciplinary research (e.g. Belcher, Claus, et al. 2019; Binder et al. 2020; Fritz et al. 2019; Jacobi et al. 2020, 2022; Lux et al. 2019). At the same time, there is concern that transdisciplinary research is less successful in developing more classical research outputs and impacts like scientific publications and their resonance in the scientific community in the form of citations (Bulten et al. 2021; Ruppert-Winkel et al. 2015; Zscheischler, Rogga, and Lange 2018).

Generally, previous comparative works find that transdisciplinary research is more successful in generating societal impact than more traditional forms of research (Belcher, Claus, et al. 2019; Jacobi et al. 2022; De Jong et al. 2016). However, previous qualitative research still struggles to causally link specific modes and impacts (Hansson and Polk 2018; Lux et al. 2019; Zscheischler et al. 2018). Although ideal-typical transdisciplinary research is aiming at unfolding impact in the societal as well as in the academic sphere (Jahn 2008; Lang et al. 2012), less research so far analyzed the scientific outputs of transdisciplinary research and its resonance in the scientific system in more detail (for exceptions see Belcher, Claus, et al. 2019; Hegger and Dieperink 2015).

Following Aim 3, this thesis sheds light on the research mode characteristics of transdisciplinary projects that can be linked to increased societal impact based on a comparative analysis of a larger number of research projects. Additionally, this chapter presents the results on how transdisciplinary research performs in the more classical research impact categories of scientific publications and citations. The quantitative findings are contrasted and facetted with the findings of the qualitative MONA in-depth study described in [A2] and the stakeholder views on research utilization that are outlined in [A3].

6.2 Linking research modes and societal impact

The analysis presented in [A2] based on 81 actual research projects shows, that all involvement characteristics that were tested in the linear regression model (early involvement of practitioners, inclusion of practitioners in project decisions, practitioners providing knowledge about the problem field, practitioners stating their values and norms) independently correlate positively with the societal impact of the research project. However, in the combined model, no general positive influence of practitioner involvement on societal outcome could be confirmed, but two selective links: The early practitioner involvement in the problem definition and/or research question definition phase, supporting the findings of De Jong et al. (2016), and the dissemination of research findings as measured by the sum of publications and activities to inform practitioners and the broader public.

The application of structured methods of knowledge integration[12] is strongly advocated in the theoretical literature to foster societal impact of research projects (Bergmann et al. 2012; Brandt et al. 2013; Fazey et al. 2014; Hoffmann et al. 2017; Scholz and Tietje 2002; Vilsmaier et al. 2015). However, the analysis underlying [A2] was not able to confirm this assumption, nor did it find a positive relationship with knowledge contributions of practitioners in general, aligning with the findings of Chambers et al. (2021).

In [A1] the five research modes that were empirically identified within 59 real inter- and transdisciplinary sustainability research projects (for an overview see Section 5 on Aim 2# Demarcation) vary with respect to their success in reaching societal impact. The cluster comparison revealed that ideal-typical transdisciplinary research (Cluster 4) shows the highest level of

[12] Methods of knowledge integration in various forms were applied in the projects in the sample of the MONA project, like for example scenario building, SWOT analysis, development and application of models, multicriteria assessment, Delphi method, stakeholder workshops or moderated meetings.

societal impact, followed by the practice-oriented Cluster 5. Both these highly interactive research mode clusters have substantially higher scores in societal impact than the less interactive, more consultative Clusters 2 and 3 and purely academic research Cluster 1. These results support the earlier findings of Belcher et al. (2019), Jacobi et al. (2022), Binder et al. (2020) and Chambers et al. (2021), who find that more intense forms of transdisciplinary research lead to more societal impact. Correspondingly, the results challenge the findings of De Jong et al. (2016) and Phillipson et al. (2012), who find that less intensive, more consulting transdisciplinary approaches showed stronger societal effects.

In accordance with the findings of [A2], the ideal-typical transdisciplinary research cluster and the practice-oriented cluster which are strongly engaging with practitioners in early project phases reach the highest societal impacts. Additionally, the results in [A1] display the highest scores for societal impact for research mode clusters that also display the highest levels of dissemination and communication efforts. This is particularly interesting because the purely academic research Cluster 1, which does not actively interact with practitioners but shows high levels of dissemination activities, has a significant amount of societal impact, even more than the moderately interactive research clusters (Clusters 2 and 3).

Involvement in defining the research problem on the one hand and the provision of understandable and applicable results on the other hand are also the two aspects most strongly mentioned by forest research stakeholders who were asked about their views on research utilization for [A3]: The stakeholders interviewed wish for research with a greater practical relevance, and demand researchers to get in contact to learn about pressing problems of the practice. With respect to dissemination, various claims were formulated that refer to the processing and communication of research results: Stakeholders call for a translation of the results into a language that is understandable to non-scientists, providing simple messages that are tailored to specific actor groups. Moreover, the scientific insights should be offered in the form of guidelines or checklists. Also mentioned was the presentation of the findings locally in the respective problem area. When it comes to knowledge (co-)production, the interviewees preferred a clear differentiation between the tasks of researchers and stakeholders, whereas researchers are seen as the producers of knowledge, while the stakeholders see themselves more in the role of raising practical problems, commenting, and implementing.

6.3 *Linking research modes and scientific impacts*

The empirical results in [A2] indicate that tow aspects, the general aim of projects to generate applicable knowledge, and the influence of practitioners on project decisions diminish academic outputs in form of scientific publications. Moreover, both impact negatively on the successful finalization of dissertation projects within sustainability science projects (for the challenges of doing a PhD in transdisciplinary research projects see Rogga and Zscheischler (2021)). A similar pattern is visible for the projects resonance in the scientific community in the form of citations of the publications: The most stable factor to explain lower citations of project publications is the degree to which the project pursued the goal to deliver applicable research results. However, the results indicate that the application of structured methods of knowledge integration impacts positively on academic outputs in form of publications.

The comparison of the research mode clusters in [A1] with respect to academic performance, finds that with increasing practice-orientation and practitioner involvement, academic outputs and impacts decrease. Cluster 1, the purely academic research cluster reaches by far the highest level of scientific publications and citations, whereas practice-oriented Cluster 5 displays very little academic output and its outputs being barely cited, demonstrating almost no interaction with the academic community in the peer reviewed publishing system. However, as argued in [A1], the projects in Cluster 5 are not the most transdisciplinary ones, but very much shaped by practice interests and activities.

6.4 *Trade-off between societal and academic impact and outputs*

In summary, the results of [A1] and [A2] display an inverse relationship between societal and academic outputs and impacts, suggesting a trade-off between these two impact spheres. In [A2] we see that the involvement of practitioners in early project phases positively affects societal impacts, while practitioner involvement was found to negatively affect both, academic publication output and citations. Moreover, the comparison of the five research mode clusters in [A1] indicates that projects with more practitioner interaction display stronger societal outputs and impacts at the cost of academic outputs and impacts, with the exception of purely academic research Cluster 1.

Rose and Maibaum (2020) generally confirm this trade-off for the specific form of transdisciplinary real-world laboratories, due to their extensive practical fieldwork with little personnel resources. Further indications of background mechanisms are delivered by Zscheischler et al.

(2018) who found that researchers and practitioners rank the development of implementable solutions as the most important success factor for transdisciplinary projects, while scientific outcomes are on the last rank. Additionally, Bulten et al. (2021) found a general insecurity among scholars on how to develop scientific publications from knowledge generated in transdisciplinary processes. In contrast, Lemaitre and Le Roux (2021) cannot confirm a trade-off between societal and academic outputs and impacts, based on an analysis of 21 biodiversity research projects. Whereas they highlight that the funding program of these projects explicitly called for “research that could reach excellence for both academic production and society/policy relevance” (Lemaitre and Le Roux 2021:31).

However, the qualitative results of the MONA in-depth study presented in [A2] offer perspective on how single projects were able to mitigate the trade-off – mainly by promoting the scientific part of interactive research projects. The following activities were observed that foster strong academic outcomes in the analyzed transdisciplinary research projects: a constant focus on producing academic results, starting to publish early in the research process, an effective division of tasks among the involved researchers, a purposeful combination of disciplinary, inter- and transdisciplinary research phases, as well as researchers with a strong individual research agenda.

6.5 Summary

The work presented here to serve Aim 3 does not establish causal links, but substantive empirical insights on relationships between research modes and respective project outcomes based on the quantitative comparative analysis of data from a larger number of actual research projects.

Generally, the results show that societal and academic outputs and impacts vary with specific project characteristics [A2] and combinations of project characteristics defined as research modes [A1]. In more detail, the results imply that more interactive research modes reach more societal impacts. In addition, selective relationships were found between the characteristics of the research process and the outcomes and impacts, which were also consistent with stakeholder expectations on research utilization [A3]: The results indicate that the involvement of practitioners in early project phases positively affects societal impacts. Moreover, societal impacts seem to be fostered by research dissemination efforts. In contrast, the results imply that a strong practice-orientation and involvement negatively affects both the number of scientific publications and the number of citations [A2].

To date, little research has related scientific and societal outcomes and impacts of transdisciplinary research. This work is the first to provide indication of a trade-off between societal and scientific outcomes and impacts based on a solid empirical foundation [A1 & A2], whereas the analysis of a qualitative subsample of the qualitative studies revealed some strategies on how to mitigate the trade-off [A2].

7 Synthesis and discussion

In the following Section the results of this dissertation work are synthesized and discussed with respect to more overarching challenges of transdisciplinary research. Lessons for the future practical implementation of transdisciplinary research are drawn as well as impulses for future study of transdisciplinary research are outlined.

7.1 The contribution of transdisciplinary research to sustainability transformations

Transdisciplinary sustainability research is conducted with the aim to contribute to the solution of sustainability problems (Klein 2014; Miller et al. 2014; Wiek et al. 2015). Still, there is little empirical evidence based on a larger number of observations about what really works for the societal impact of transdisciplinary research (Pärli et al. 2022). The empirical findings of this dissertation show that more interactive forms of sustainability research generally achieve greater societal impact than projects that have less intensive contact with practitioners [A1]. In addition, this work provides empirical indication which determinants most strongly foster societal impact: the early involvement of practitioners to collaboratively define research problems and questions, and the targeted dissemination of results [A2].

These findings generally support the claimed effectiveness of transdisciplinary research for providing socially relevant, applicable knowledge, and to a greater extent than less interactive or more conventional forms of research, as also previous studies have also shown (Belcher, Claus, et al. 2019; Binder et al. 2020; Jacobi et al. 2022). Hence, these results may encourage the further promotion of transdisciplinary research by funding agencies, like e.g. the German Federal Ministry of Education and Research (BMBF) which are aiming to trigger more direct societal benefits of science by mission-oriented research funding (BMBF 2020). Moreover, the results on the effectiveness of the early involvement of practitioners support claims to provide funding for researchers and practitioners in a project development and proposal phase (Binder et al. 2020; Hoffmann et al. 2019; Landry, Amara, and Lamari 2001).

However, the theory and practice of transdisciplinarity currently mainly focusses on the *interaction model* of knowledge utilization (Hoffmann et al. 2019; Landry et al. 2001), concentrating on productive interactions between researchers and practitioners during the research process as the cause for research uptake (Spaapen and van Drooge 2011). Yet, the results of this work demonstrate additionally targeted dissemination and research communication as an effective way to move knowledge into application and thus support the *dissemination model* of knowledge utilization (Hoffmann et al. 2019; Landry et al. 2001). The *dissemination model* of knowledge utilization highlights the translation of results and targeted distribution as a cause for research application. Additionally, the dissemination and targeted research communication can expand the impact area of projects to actors and institutions at other governance levels beyond the project context [A2]. Hence, dissemination strategies and efforts should be highlighted more strongly as integral aspects of an integrative transdisciplinary process (Knickel et al. 2019; Lam et al. 2021; Nagy et al. 2020).

Nevertheless, the regression model to analyze the relationship between characteristics of transdisciplinary research and societal impact that was applied in [A2] was only able to explain roughly about 30% of the variance of societal impact between the projects. Hence, this work wants to motivate future research to look at further determinants of the research process that might influence successful societal outcomes like for example general project management strategies (Polk 2015), group dynamics, power and trust (Binder et al. 2020; Fritz and Meinherz 2020) or the overarching social and political context in which the research project is embedded and which may also impact on the application of the results (Lam et al. 2021; Nagy et al. 2020; Schneider et al. 2022). Furthermore, this work provides a large indicator set, tailored to grasp the characteristics of these new modes of research and their various outcomes. Yet, due to reasons of data availability, as the societal output and impact variables are mostly based on open text material from the project leaders, there is an undercoverage of actual outputs of the projects in the sense of prototypes or products, strategies, concepts, and measures. While this aspect is covered indirectly through whether the research results were disseminated via publications for practice, guidelines, or presented at practice events, there is a blind spot for what the result of the project actually was. Hence, future large-N research should target this gap and lay a specific focus on these real outcomes and (potential) sustainability solutions (Williams and Robinson 2020).

Generally, to foster the effectiveness of transdisciplinary research for sustainability problem solving, future research should expand the quantitative comparative analysis of which of the multiple characteristics of transdisciplinary research contribute to societal impact and how these characteristics interplay (Lawrence et al. 2022; Pärli et al. 2022). And since quantitative comparative research, as conducted for this dissertation work, is labor intense, all available data should be used to investigate on the topic: the last evaluation of the sustainability research funding line of the German federal ministry of education and research (FONA) for example collected the respective information on a larger number of projects but missed to investigate on links between modes and impacts (Bührer et al. 2020). In qualitative research, work using a theory of change (TOC) approach has been most successful in revealing mechanisms between modes and impacts (Belcher, Claus, et al. 2019; Schneider et al. 2019) so far. These qualitative findings should be used as an asset to inform the operationalization of future large-N studies. Finally, qualitative and quantitative studies and evaluations should be more often combined and should additionally give greater consideration to practitioners' views and experiences as they do not always follow the logics of academic conceptualizations of integrative research and research utilization as shown in [A3].

7.2 The embedding of transdisciplinary research in the academic system

The empirical results of this thesis show that more interactive research projects in the sample produce substantially less scientific publications than projects that apply more 'classical' research approaches. Additionally, the resonance of the research results of these projects within the scientific community in the form of uptake of the publications as references in other scientific work is considerably lower.

Two aspects related to that finding raise concern: First, academic careers and the distribution of funding grants is still strongly linked to standard evaluation indicators of scientific performance in the form of publications and citations (DFG 2022). Hence, transdisciplinary research scoring lower with respect to these indicators, can hinder transdisciplinary researchers in advancing their careers within the academic system (Jaeger-Erben et al. 2018; Rogga and Zscheischler 2021).

The second concern relates to the alignment of transdisciplinary research with overarching rulesets of the scientific system:

Although there are no universally valid criteria for scientific research, there are fundamental and overarching procedures in the scientific system, that maintain scientific quality (Henze 2021). The baseline of these rules is the cumulative structure of science and the organized critical contestation of research results within the scientific community, which are explicated by Popper (2005) as the *critical method* and Merton (1942) as *organized skepticism*: New knowledge has to build upon previous knowledge and has to be contested by other researchers in systematic procedures to review and assess the new knowledge in open debates within the academic system (Merton 1942; Popper 2005) – while these debates are mainly taking part in written forms.

Accordingly, all transdisciplinary research that is not published, is not available for critical contestation[13], and is moreover not systematically documented and accessible for future research to build on, which hinders knowledge cumulation (Kueffer et al. 2007; Newig and Rose 2020; Wuelser et al. 2021). Hence, this dissertation work wants to call for efforts to foster the critical contestation and the structured documentation of insights of transdisciplinary research. A way forward might be the agreement on and the application of minimum reporting standards for transdisciplinary research based on already accepted quality criteria (Belcher et al. 2016; Bergmann et al. 2005; Knickel et al. 2019) – especially as Bulten et al. (2021) discovered a general insecurity among researchers regarding the publication of transdisciplinary results. Furthermore, efforts should be taken to make transdisciplinary research insights systematically accessible not only for future research projects but also for practice-driven development projects, e.g., in online data bases like Zenodo[14] or the 'solutions for a healthy planet' database Panorama[15] which do not necessarily have to be located inside the classic scientific publishing system.

7.3 The role of practitioner knowledge

Knowledge-exchange processes between science and practice are at the heart of many conceptualizations of transdisciplinary research under the terms of 'knowledge integration' (Bergmann et al. 2012; Defila and Di Giulio 2015; Pohl et al. 2021), 'knowledge co-production' (Chambers et al. 2021; Norström et al. 2020) and 'co-creation of knowledge' (Lang et al. 2012; Polk 2015).

---

[13] One can of course argue that transdisciplinary is contested by the direct exchange with societal actors on whether the results are of use to them. Nevertheless, practitioners will most likely not be able to assess the credibility of the scientific procedures of how the knowledge is created.

[14] https://zenodo.org, last visited 21.01.2023.

[15] https://panorama.solutions/en, last visited 21.01.2023.

However, the actual impact of practitioner knowledge on the outputs and impacts of transdisciplinary processes is still unclear (Chambers et al. 2021). While previous qualitative research by Fritz et al. (2019) identify the provision of knowledge about the practice context as one step in impact pathways that lead to sustainability transformations, the analysis underlying this dissertation work was not able to confirm this finding based on a larger number of projects: The regression models in [A2] were not able to detect a relationship between practitioner knowledge contributions and societal impacts, while the results even display a negative effect of practitioner knowledge contributions on scientific publications and citations. Additionally, the qualitative findings of [A3] indicate that stakeholders involved in research settings favor a classical distribution of work, where knowledge is produced by researchers and the practitioner role is to raise practical problems to initiate the research, and to set findings into perspective.

However, in this thesis, knowledge is operationalized very broadly, without a refined conceptualization, whereas the co-production of knowledge is a complex cognitive process (Pohl et al. 2021). Thus, the role of practitioner knowledge in transdisciplinary research warrants closer inspection, based on a more refined conceptualization of what is understood as knowledge and how it is transmitted between different actors. Of specific interest in this respect would be to trace carefully what exactly practitioners provide as knowledge, how this is processed throughout the further transdisciplinary research process and how these inputs are contributing to the outcomes of the research project through in-depth accompanying research. A promising way to structure the analysis would be to trace the knowledge contributions along the three research phases of the ideal-typical transdisciplinary process (Jahn 2008; Lang et al. 2012) and in terms of content, related to the three types of knowledge underlying transformative research: System knowledge, target knowledge, and transformation knowledge (CASS & ProClim- 1997; Kueffer, Schneider, and Wiesmann 2019).

Besides, the empirical results of [A2] show that at least for the number of scientific publications, the application of structured methods of knowledge integration have a significant positive effect. Accordingly, one lever to also foster academic publication output of transdisciplinary research, could be to investigate in more depth how methods of knowledge integration can contribute or facilitate not only societal but also academic outputs and impacts.

7.4 The trade-off between societal and academic impacts

Ideally, transdisciplinary research is aiming at contributing to societal as well as scientific problem solving (D'Este et al. 2018; Jahn 2008). However, very little research to date has targeted and related both societal and scientific outcomes of transdisciplinary research (for an exception see Hegger and Dieperink 2015 and Lemaitre and Le Roux 2021). The results of this thesis show that practitioner involvement in research fosters societal impacts, while the results also indicate that practitioner interactions negatively affect the publication outputs and citations [A1]. Hence, this work describes a tension or trade-off between societal and academic impact with projects involving practitioners more intensely reaching greater societal impact at the cost of academic outputs and impacts impact [A1 & A2].

The literature provides a set of explanations that describe mechanisms behind the observed trade-of: D'Este et al. (2018) mention the funding context as crucial for the choice of research modes as well as the orientation towards societal versus academic impact. This influence is also supported by empirical findings of this dissertation work: As described in [A1] and [A2], projects from mission-oriented research funding (German Federal Ministry of Education and Research, BMBF), which tenders often explicitly call for societally applicable outcomes and partly even request a research mode involving societal actors, display stronger societal impacts. Whereas projects from bottom-up funding (German Research Foundation, DFG) reach more academic outputs and impact, as academic excellence and classical criteria of research evaluation are crucial for further funding from this institution. Another underlying mechanism, that should be observed empirically by future research is the assumption that organizational conditions might shape the choice of modes and impact aims, as organizations differ in their "climate" of openness for societally-oriented research (D'Este et al. 2018). Furthermore, D'Este et al. (2018), Misra et al. (2015) and Hilger et al. (2021) highlight that also the individual antecedents of researchers determine which priorities are set between societal and academic research outputs as well as interest in engagement in transdisciplinary research in general.

However, there were also projects observed in the context of this dissertation that reached both goals to a certain degree, and the qualitative in-depth study [A2] discovered strategies for how projects promoted scientific work alongside practical work. This dissertation likes to encourage future research to further investigate on how to mitigate the trade-off and explicitly search for mechanisms and conditions that support the dual aim of transdisciplinary research to produce both strong societally and academically relevant outcomes. Thereby, future research should use classical research indicators like publications and citations as they are still widely applied in research governance (DFG 2022), but also assess other contributions of transdisciplinary research to academia which are for example currently explored by a research project of the tdAcademy[16].

Conversely, the trade-off between societal and academic impacts in the light of the research modes in [A1] can also serve as an argument for plurality of research modes within sustainability science, to balance their respective advantages and boundaries. As Lawrence et al. state, transdisciplinarity is not meant to replace all other forms of research, but to "augment (…) research conducted using long-standing disciplinary and interdisciplinary scientific methods" (Lawrence et al. 2022:45).

7.5 Methodological reflections and limitations

This thesis followed a mixed method design to expand the depth and breadth of the analysis of transdisciplinary research in sustainability science, in which the larger part of the argumentation is based on the results of quantitative research. The application of a deductive, structured approach to the analysis of transdisciplinary research can generally be criticized for not being able to capture all the complex facets of transdisciplinarity and for not paying sufficient attention to the specifics of each research project and its individual results[17]. And as scientific practices align to evaluation criteria over time (Alkin and King 2016; Hemlin 1996), there is the risk of limiting the diversity and specificity of transdisciplinary projects if highly structured approaches become the predominant way of analyzing transdisciplinary research. Hence, this thesis likes to encourage future research to integrate quantitative and qualitative approaches in innovative and balanced ways. However, systematic large-N approaches are a prerequisite for further structuring the research field of sustainability science, for exploring different approaches within transdisciplinary research and thus continuing the delineation efforts of Brandt et al. (2013), Tribaldos et al. (2020), Férnandez González et al. (2021) and this work.

This work aimed at connecting and contrasting perspectives of researchers and practitioners. While this led to valuable confrontation and illustration of the quantitative results, the gain of knowledge would have been even bigger, if the conceptual and empirical foundation of [A3] would have been more closely aligned with [A1] and [A2]. Furthermore, this work is still conceptually based on a strong divide between science and society as two societal subsystems and

[16] https://td-academy.org/en/tdacademy/topic-lines/topic-line-2-scientific-effects2, last visited 21.01.2023.
[17] One principal investigator of a project in the MONA sample did not participate in the survey for this reason.

a duality between researchers and practitioners. Hence, future research should develop conceptual innovations to overcome this divide (Dressel 2022; Hilger et al. 2021) and to look explicitly at intermediary actors, like consultants or entrepreneurial researchers.

It is to note that this work is strongly referring to the German and Central European context and discourse: The data on which this dissertation is based were collected exclusively in the German context by examining research projects that were funded in the German research system and by interviewing German actors who participated in a German case study. Moreover, this work is strongly based on the ideal-typical model of transdisciplinary research promoted by Jahn (2008), Bergmann et al. (2012) and Lang et al. (2012), which is predominantly discussed and applied in the central European discourse on transdisciplinary research (e.g., Avelino 2017; Norström et al. 2020; Sachs et al. 2019; Schaltegger et al. 2013). Also, the majority of comparable empirical studies that were used to contextualize the findings of this thesis were conducted in a Central European context (Binder et al. 2020; Bulten et al. 2021; De Jong et al. 2016; Phillipson et al. 2012; Zscheischler and Rogga 2015). As transdisciplinary research is context specific, it is crucial to reflect the relevance and transferability of the findings of this work for transdisciplinary research in other world regions with different political and cultural settings (Chilisa 2017; Lam et al. 2021; Moewaka Barnes et al. 2021; Pärli et al. 2022; Schneider et al. 2022).

In many conceptualizations interdisciplinary collaboration is an integral aspect of the transdisciplinary research process (Klein 2014; Klein, Baptista, and Danilo 2022; Lang et al. 2012). In this work, interdisciplinarity is touched only very at the side in [A1] due to limitations in data availability[18]. While there is a huge body of literature on interdisciplinary collaborations in the field of team science (Hall et al. 2018; Hall, Vogel, and Croyle 2019), little research so far analyses the challenges of working inter- and transdisciplinary alongside in the process (Baptista 2023). Hence, there is space for future research to come up with effective research designs to explicitly target this link.

[18] To quantify the degree of interdisciplinarity of a research project, first all individual members of the research project were identified. Subsequently, their last professional qualification at the time of the project was searched in documents or online. This information on the level of the individual project member was then aggregated for the whole project as percentual shares of disciplinary background (see online supplementary material of Article 1 [A1_OSM]). The steps undertaken to identify this indicator are prone to missing values because for some projects it was not possible to get a comprehensive member list, or it was not possible to research the qualification of one or more members of the research project. If the information of at least one team member was missing, the indicator was not exact, and the data could not be used for analyses on the project level. For this reason, the in-depth analysis of interdisciplinarity in the context of transdisciplinary research could not take place as planned in this thesis.

This thesis is mainly looking at research *effectiveness* in the sense of delivering societal as well as academic outputs and impacts which may possibly contribute "to positive change in the social, economic, and/or environmental problem context" (Belcher et al. 2016:12). Hence, it deals only marginally with *legitimacy* in the sense of whether the transdisciplinary process and its outcomes is unbiased and meets standards of "political and procedural fairness" (Cash et al. 2002:5) by considering values, interests and affectedness (Belcher, Ramirez, et al. 2019; Cash et al. 2002; Fritz and Binder 2020; Newig and Kvarda 2012). Nevertheless, the research approach and indicators applied in this work could be extended to additionally cover legitimacy more strongly in future studies.

Finally, the projects investigated for [A1] and [A2] date back further in time. Nevertheless, the results can be interpreted as a first description of archetypes of interactive research within sustainability science and a snapshot of the German research landscape at that time. However, an update of the study including projects from other world regions would provide valuable insights into how the field has developed over the past decade.

8 Conclusions

This work contributes to a better understanding of the actual application of transdisciplinary research in sustainability science and the determinants that shape the contributions of transdisciplinary research to the tackling of societal problems and to scientific knowledge production. Overall, this work demonstrates the value and potential of transdisciplinary research to generate societal impacts on the way to sustainability problem solving. Nevertheless, it also uncovers challenges with respect to the contribution of transdisciplinary research to scientific progress and its accessibility for future research. This was reached by the application of a mixed methods approach, that complements larger efforts of quantitative research with qualitative research and connects the researcher and practitioner perspective on transdisciplinary research.

8.1 Scientific contribution

Firstly, this work offers innovation in the field of measurability and evaluation of transdisciplinary research by providing a large set of indicators to track and depict transdisciplinary research and its outcomes in a more structured way and is a first example of the adaptation of the Case Survey Method (Yin and Heald 1975) in this field. Hence, it responds to the claims for options to describe and evaluate transdisciplinary research on a larger scale beyond classical indicators of research performance (Belcher et al. 2016; Krainer and Winiwarter 2016; Wolf et al. 2014).

Secondly, this work brought forward the conceptual clarification of transdisciplinary research in sustainability science by the theoretical and empirical demarcation of transdisciplinary research from other, neighboring approaches and research practices and by contrasting it with the perspectives of practitioners on interactive research settings. In this, a strong contribution to the field is the discovery and description of five empirically grounded research modes within sustainability science. It refines that ideal-typical transdisciplinary research goes beyond less integrative, more consultatory research approaches, but is also not equal to pure practitioner-led research and must be distinguished from what is conceptualized as applied research.

As a third contribution, this work extended the previous understanding of the relationship between research modes and research mode characteristics and societal as well as scientific outputs and impacts of transdisciplinary research. This work goes beyond previous studies that mostly looked at societal as well as academic outputs and impacts separately and demonstrated with systematically obtained empirical evidence a trade-off between scientific and societal outputs and impacts between more and less interactive research modes.

8.2 Practical implications

Although the overarching aim of this thesis was analytical, there are certainly aspects that can be of interest for researchers in the planning, application, and reflection of transdisciplinary research as well as for funding agencies in the conceptualization of research programs:

The finding that early involvement of practitioners and the dissemination efforts foster societal impact can help researchers to highlight these two aspects in the design of their future projects accordingly, especially as both aspects resonate strongly with practitioner expectations of such processes. Additionally, funding agencies can support these two aspects by the targeted provision of funding for example for both a pre-phase for joint problem framing and definition of the research question and the distribution and communication of research results. Moreover, the five research modes identified in this work offer a momentum for researchers to reflect on past and current projects. The identified trade-off between societal and academic impact highlights the need for researchers to actively prioritize between the intended outcomes of integrative research projects. For research funders the five research modes might inform the composition of research programs, by selecting projects of different modes to balance the trade-off between societal and scientific outcomes and to foster diverse outcomes.

8.3 Future research and way forward

The following ideas for future research emerge from this work: For the structured quality assurance and comparative evaluation of transdisciplinary research, there lies a huge potential in the consolidation of the various sets of evaluation criteria that have been developed in recent years and which also encompass this work. This could help to professionalize transdisciplinary research, facilitate future large-N analysis of transdisciplinary research, and deliver evidence-based arguments for its future funding. Furthermore, more integrative research on transdisciplinary research that combines qualitative and quantitative approaches, involves the practitioner perspective, and mitigates the conceptual divide between researchers and practitioners and science and practice at large can further deepen and substantiate the understanding of what characteristics do influence the diverse impacts of transdisciplinary research. Particular attention should be paid to the role of practitioner knowledge for the social and academic outcomes of transdisciplinary projects, which should best be analyzed through in-depth accompanying research. Generally, the study and discussion of transdisciplinary sustainability research must go further beyond the Central European context and investigate transdisciplinary research in other political and cultural settings – to test the transferability of the results of this work in other contexts, but also to reflect on Eurocentric understandings of science and overcome post- and neocolonial entanglements (Chilisa 2017; Lam et al. 2020). Furthermore, this research indicates that many results and developed solutions of transdisciplinary research remain unpublished – at least in a scientific way. Hence, this work likes to initiate efforts that support transdisciplinary researchers in the systematic documentation and publication of research results. On the one hand, this would enable knowledge cumulation (Newig and Rose 2020) and critical contestation (Merton 1942; Popper 2005) within in transdisciplinary sustainability science. On the other hand, it would also make the various valuable sustainability solutions that have been discovered accessible to a wider audience and beyond the scope of the project.

9 References

Alkin, Marvin C. and Jean A. King. 2016. "The Historical Development of Evaluation Use." *American Journal of Evaluation* 37(4):568–79.

Angrist, Joshua D. and Jörn-Steffen Pischke. 2009. *Mostly Harmless Econometrics: An Empiricist´s Compagnion*. Princeton, Oxford: Princeton University Press.

Avelino, Flor. 2017. "Power in Sustainability Transitions: Analysing Power and (Dis)Empowerment in Transformative Change towards Sustainability." *Environmental Policy and Governance* 27(6):505–20.

Baptista, Bianca Vienni. 2023. "Disentangling Interdisciplinarity and Transdisciplinarity: The Beauty of Differing Definitions." Pp. 59–76 in *Theory and Practice in the Interdisciplinary Production and Reproduction of Scientific Knowledge: ID in the XXI Century*, edited by O. Pombo, J. Jesuíno, and K. Gärtner. Cham: Springer International Publishing.

Barnett, Jon, Sergio Jarillo, Stephen E. Swearer, Catherine E. Lovelock, Andrew Pomeroy, Teresa Konlechner, Elissa Waters, Rebecca L. Morris, and Ryan Lowe. 2022. "Nature-Based Solutions for Atoll Habitability." *Philosophical Transactions of the Royal Society B* 377(1854):20210124.

Beck, Silke. 2011. "Moving beyond the Linear Model of Expertise? IPCC and the Test of Adaptation." *Regional Environmental Change* 11(2):297–306.

Becker, Egon and Thomas Jahn. 2006. *Soziale Ökologie. Grundzüge Einer Wissenschaft von Den Gesellschaftlichen Naturverhältnissen*. Frankfurt, New York: Campus.

Becker, Egon, Thomas Jahn, Diana Hummel, Immanuel Stiess, and Peter Wehling. 2001. "Sustainability: A Cross-Disciplinary Concept for Social-Ecological Transformations." Pp. 147–52 in *Transdisciplinarity: Joint problem solving among science, technology and society*, edited by J. Thompson Klein, W. Grossenbacher-Mansuy, R. Häberli, A. Bill, R. W. Scholz, and M. Welti. Basel, Boston, Berlin: Birkhäuser Verlag.

Beland Lindahl, Karin and Erik Westholm. 2014. "Transdisciplinarity in Practice: Aims, Collaboration and Integration in a Swedish Research Programme." *Journal of Integrative Environmental Sciences* 11(3–4):155–71.

Belcher, Brian M., Rachel Claus, Rachel Davel, and Luisa F. Ramirez. 2019. "Linking Transdisciplinary Research Characteristics and Quality to Effectiveness: A Comparative Analysis of Five Research-for-Development Projects." *Environmental Science & Policy* 101:192–203.

Belcher, Brian M., Luisa F. Ramirez, Rachel Davel, and Rachel Claus. 2019. "A Response to Hansson and Polk (2018) "Assessing the Impact of Transdisciplinary Research: The Usefulness of Relevance, Credibility, and Legitimacy for Understanding the Link between Process and Impact." *Research Evaluation* 28(2):196–201.

Belcher, Brian M., Katherine E. Rasmussen, Matthew R. Kemshaw, and Deborah A. Zornes. 2016. "Defining and Assessing Research Quality in a Transdisciplinary Context." *Research Evaluation* 25(1):1–17.

Bergmann, Matthias, Bettina Brohmann, Esther Hoffmann, M. Celine Loibl, Regine Rehaag, Engelbert Schramm, and Jan-Peter Voss. 2005. "Quality Criteria of Transdisciplinary Research. A Guide for the Formative Evaluation of Research Projects." *Institut Für Sozial-Oekologische Forschung (ISOE)*.

Bergmann, Matthias, Tobias Knobloch, Wolfgang Krohn, Christian Pohl, and Engelbert

Schramm. 2012. *Methods for Transdisciplinary Research. A Primer for Practice*. Frankfurt, New York: Campus.

Bergmann, Matthias, Niko Schäpke, Oskar Marg, Franziska Stelzer, Daniel J. Lang, Michael Bossert, Marius Gantert, Elke Häußler, Editha Marquardt, Felix M. Piontek, Thomas Potthast, Regina Rhodius, Matthias Rudolph, Michael Ruddat, Andreas Seebacher, and Nico Sußmann. 2021. "Transdisciplinary Sustainability Research in Real-World Labs: Success Factors and Methods for Change." *Sustainability Science* 16(2):541–64.

Binder, Claudia R., Iris Absenger-Helmli, and Thorsten Schilling. 2015. "The Reality of Transdisciplinarity: A Framework-Based Self-Reflection from Science and Practice Leaders." *Sustainability Science* 10(4):545–62.

Binder, Claudia R., Livia Fritz, Ralph Hansmann, Andreas Balthasaar, and Zilla Roose. 2020. "Increasing the Relevance of Science for Practice and Practice for Science: Quantitative Empirical Insights." *Science and Public Policy* 47(6):772–87.

BMBF. 2015. "Sozial-Ökologische Forschung. Förderkonzept Für Eine Gesellschaftsbezogene Nachhaltigkeitsforschung 2015 - 2020." *Bundesministerium Für Bildung Und Forschung*.

BMBF. 2020. "Forschung Für Nachhaltigkeit. Eine Strategie Des Bundesministeriums Für Bildung Und Forschung." *Bundesministerium Für Bildung Und Forschung*.

Boaz, Annette, Huw Davies, Alec Fraser, and Sandra Nutley. 2019. *What Works Now? Evidence-Informed Policy and Practice*. Bristol: Policy Press.

Böcher, Michael and Max Krott. 2014. "The RIU Model as an Analytical Framework for Scientific Knowledge Transfer: The Case of the 'Decision Support System Forest and Climate Change.'" *Biodiversity and Conservation* 23(14):3641–56.

Brandt, Patric, Anna Ernst, Fabienne Gralla, Christopher Luederitz, Daniel J. Lang, Jens Newig, Florian Reinert, David J. Abson, and Henrik Von Wehrden. 2013. "A Review of Transdisciplinary Research in Sustainability Science." *Ecological Economics* 92:1–15.

Brink, Ebba, Christine Wamsler, Maria Adolfsson, Monica Axelsson, Thomas Beery, Helena Björn, Torleif Bramryd, Nils Ekelund, Therese Jephson, and Widar Narvelo. 2018. "On the Road to 'Research Municipalities': Analysing Transdisciplinarity in Municipal Ecosystem Services and Adaptation Planning." *Sustainability Science* 13(3):765–84.

Brown, David L. and Rajesh Tandon. 1983. "Ideology and Political Economy in Inquiry: Action Research and Participatory Research." *The Journal of Applied Behavioural Science* 19(3):277–94.

Bührer, Susanne, Rainer Walz, Sarah Seus, Michael Astor, Thomas Stehnken, and Fabian Malik. 2020. "Evaluation Der BMBF-Rahmenprogramme Forschung Für Die Nachhaltigkeit FONA 1 (2005-2009) & Forschung Für Nachhaltige Entwicklungen FONA 2 (2010-2014)." *Studie/Gutachten Im Auftrag Des Bundesministeriums Für Bildung Und Forschung (BMBF)*.

Bullock, R. J. 1986. "A Meta-Analysis Method for OD Case Studies." *Group & Organization Management* 11(1–2):33–48.

Bulten, Ellen, Laurens K. Hessels, Michaela Hordijk, and Andrew J. Segrave. 2021. "Conflicting Roles of Researchers in Sustainability Transitions: Balancing Action and Reflection." *Sustainability Science* 16:1269–83.

Bunders, Joske F. G., Jacqueline E. W. Broerse, Florian Keil, Christian Pohl, Roland W. Scholz, and Marjolein B. M. Zweekhorst. 2010. "How Can Transdisciplinary Research

Contribute to Knowledge Democracy?” Pp. 125–52 in *Knowledge Democracy: Consequences for Science, Politics, and Media*, edited by R. J. in ’t Veld. Heidelberg, Dordrecht, London, New York: Springer.

Caniglia, Guido, Niko Schäpke, Daniel J. Lang, David J. Abson, Christopher Luederitz, Arnim Wiek, Manfred D. Laubichler, Fabienne Gralla, and Henrik von Wehrden. 2017. “Experiments and Evidence in Sustainability Science: A Typology.” *Journal of Cleaner Production* 169:39–47.

Cash, David, William C. Clark, Frank Alcock, Nancy M. Dickson, Noelle Eckley, and Jill Jäger. 2002. “Salience, Credibility, Legitimacy and Boundaries: Linking Research, Assessment and Decision Making.” *John F. Kennedy School of Government Harvard University Faculty Research Working Paper Series*.

Cash, David W., William C. Clark, Frank Alcock, Nancy M. Dickson, Noelle Eckley, David H. Guston, Jill Jäger, and Ronald B. Mitchell. 2003. “Knowledge Systems for Sustainable Development.” *Proceedings of the National Academy of Sciences of the United States of America* 100(14):8086–91.

CASS & ProClim-. 1997. *Forschung Zu Nachhaltigkeit Und Globalem Wandel – Wissenschaftspolitische Visionen Der Schweizer Forschenden*. Bern.

Chambers, Josephine M., Carina Wyborn, Melanie E. Ryan, Robin S. Reid, Maraja Riechers, Anca Serban, Nathan J. Bennett, Christopher Cvitanovic, María E. Fernández-Giménez, Kathleen A. Galvin, Bruce E. Goldstein, Nicole L. Klenk, Maria Tengö, Ruth Brennan, Jessica J. Cockburn, Rosemary Hill, Claudia Munera, Jeanne L. Nel, Henrik Österblom, Angela T. Bednarek, Elena M. Bennett, Amos Brandeis, Lakshmi Charli-Joseph, Paul Chatterton, K. Curran, Pongchai Dumrongrojwatthana, América Paz Durán, Salamatu J. Fada, Jean David Gerber, Jonathan M. H. Green, Angela M. Guerrero, Tobias Haller, Andra Ioana Horcea-Milcu, Beria Leimona, Jasper Montana, Renee Rondeau, Marja Spierenburg, Patrick Steyaert, Julie G. Zaehringer, Rebecca Gruby, Jon Hutton, and Tomas Pickering. 2021. “Six Modes of Co-Production for Sustainability.” *Nature Sustainability* 4(11):983–96.

Chilisa, Bagele. 2017. “Decolonising Transdisciplinary Research Approaches: An African Perspective for Enhancing Knowledge Integration in Sustainability Science.” *Sustainability Science* 12(5):813–27.

Christophersen, Timo and Christian Grape. 2009. “Die Erfassung Latenter Konstrukte Mit Hilfe Formativer Und Reflektiver Messmodelle.” Pp. 103–18 in *Methodik der empirischen Forschung*, edited by S. Albers, D. Klapper, U. Konradt, A. Walter, and J. Wolf. Wiesbaden: Gabler Verlag.

Clark, Nancy, Ingrid Handlovsky, and Deborah Sinclair. 2015. “Using Reflexivity to Achieve Transdisciplinarity in Nursing and Social Work.” Pp. 142–58 in *Transforming Addiction - Gender, Trauma, Transdisciplinarity*, edited by L. Greaves, N. Poole, and E. Boyle. New York: Routledge.

Clark, William C. and Nancy M. Dickson. 2003. “Sustainability Science: The Emerging Research Program.” *Proceedings of the National Academy of Sciences of the United States of America* 100(14):8059–61.

D’Este, Pablo, Irene Ramos-Vielba, Richard Woolley, and Nabil Amara. 2018. “How Do Researchers Generate Scientific and Societal Impacts? Toward an Analytical and Operational Framework.” *Science and Public Policy* 45(6):752–63.

Defila, Rico and Antonietta Di Giulio. 2015. “Integrating Knowledge: Challenges Raised by the 'Inventory of Synthesis.'" *Futures* 65:123–35.

Defila, Rico, Antonietta Di Giulio, and Michael Scheuermann. 2006. *Forschungsverbundmanagement. Handbuch Für Die Gestaltung Inter- Und Transdisziplinärer Projekte*. Zürich: vdf Hochschulverlag AG ETH Zürich.

DFG. 2022. "Academic Publishing as a Foundation and Area of Leverage for Research Assessment." *Deutsche Forschungsgemeinschaft*.

Dickinson, Janis L., Jennifer Shirk, David Bonter, Rick Bonney, Rhiannon L. Crain, Jason Martin, Tina Phillips, and Karen Purcell. 2012. "The Current State of Citizen Science as a Tool for Ecological Research and Public Engagement." *Frontiers in Ecology and the Environment* 10(6):291–97.

Djenontin, Ida Nadia S. and Alison M. Meadow. 2018. "The Art of Co-Production of Knowledge in Environmental Sciences and Management: Lessons from International Practice." *Environmental Management* 61(6):885–903.

Dressel, Markus. 2022. "Models of Science and Society: Transcending the Antagonism." *Humanities and Social Sciences Communications* 9(1):1–16.

Duea, Stephanie R., Emily B. Zimmerman, Lisa M. Vaughn, Sónia Dias, and Janet Harris. 2022. "A Guide to Selecting Participatory Research Methods Based on Project and Partnership Goals." *Journal of Participatory Research Methods* 3(1):35799626.

Enengel, Barbara, Andreas Muhar, Marianne Penker, Bernhard Freyer, Stephanie Drlik, and Florian Ritter. 2012. "Co-Production of Knowledge in Transdisciplinary Doctoral Theses on Landscape Development – An Analysis of Actor Roles and Knowledge Types in Different Research Phases." *Landscape and Urban Planning* 105(1–2):106–17.

ESF. 2012. "The Challenges of Impact Assessment Working Group 2: Impact Assessment." *European Science Foundation*.

Fazey, Ioan, Lukas Bunse, Joshua Msika, Maria Pinke, Katherine Preedy, Anna C. Evely, Emily Lambert, Emily Hastings, Sue Morris, and Mark S. Reed. 2014. "Evaluating Knowledge Exchange in Interdisciplinary and Multi-Stakeholder Research." *Global Environmental Change* 25(1):204–20.

Fernández González, Claudia, Guillaume Ollivier, and Stéphane Bellon. 2021. "Transdisciplinarity in Agroecology: Practices and Perspectives in Europe." *Agroecology and Sustainable Food Systems* 45(4):523–50.

Freire, Paolo. 1974. "Conscientisation." *CrossCurrents* 24(1):23–31.

Fritz, Livia. 2020. "The Politics of Participation in Transdisciplinary Sustainability Research: An Analysis of Knowledge, Values and Power at the Science-Society Interface." Thesis at École polytechnique fédérale de Lausanne.

Fritz, Livia and Claudia R. Binder. 2020. "Whose Knowledge, Whose Values? An Empirical Analysis of Power in Transdisciplinary Sustainability Research." *European Journal of Futures Research* 8(1):1–20.

Fritz, Livia and Franziska Meinherz. 2020. "Tracing Power in Transdisciplinary Sustainability Research: An Exploration." *GAIA - Ecological Perspectives for Science and Society* 29(1):41–51.

Fritz, Livia, Thorsten Schilling, and Claudia R. Binder. 2019. "Participation-Effect Pathways in Transdisciplinary Sustainability Research: An Empirical Analysis of Researchers' and Practitioners' Perceptions Using a Systems Approach." *Environmental Science & Policy* 102:65–77.

Früh, Werner. 2017. *Inhaltsanalyse: Theorie Und Praxis*. 9th ed. Konstanz: UVK.

Funtowicz, Silvio O. and Jerome R. Ravetz. 1993. "Science for the Post-Normal Age." *Futures* 25(7):739–55.

Gibbons, Michael. 1999. "Science's New Social Contract with Society." *Nature* 402(6761 SUPPL. 1):C81–84.

Gibbons, Michael, Camille Limoges, Simon Schwartzman, Helga Nowotny, Peter Scott, and Martin Trow. 1994. *The New Production of Knowledge: The Dynamics of Science and Research in Contemporary Societies*. Los Angeles: SAGE Publications Ltd.

Giessen, Lukas, Daniela Kleinschmit, and Michael Böcher. 2009. "Between Power and Legitimacy — Discourse and Expertise in Forest and Environmental Governance." *Forest Policy and Economics* 11(5–6):452–53.

Greene, Jennifer C., Valerie J. Caracelli, and Wendy F. Graham. 1989. "Toward a Conceptual Framework for Mixed-Method Evaluation Designs." *Educational Evaluation and Policy Analysis* 11(3):255–74.

Grundmann, Reiner. 2009. "The Role of Expertise in Governance Processes." *Forest Policy and Economics* 11(5–6):398–403.

Grunwald, Armin. 2015. "Transformative Science - A New Order in Academia?" *Gaia* 24(1):17–20.

Guimarães Pereira, Ângela, Sofia Guedes Vaz, and Sylvia Tognetti. 2017. *Interfaces between Science and Society*. Taylor & Francis.

Gura, Trisha. 2013. "Citizen Science: Amateur Experts." *Nature* 496(7444):259–61.

Hall, Kara L., Amanda L. Vogel, and Robert T. Croyle. 2019. *Strategies for Team Science Success*. Cham: Springer International Publishing.

Hall, Kara L., Amanda L. Vogel, Grace C. Huang, Katrina J. Serrano, Elise L. Rice, Sophia P. Tsakraklides, and Stephen M. Fiore. 2018. "The Science of Team Science: A Review of the Empirical Evidence and Research Gaps on Collaboration in Science." *American Psychologist* 73(4):532–48.

Hall, Kara L., Amanda L. Vogel, Brooke A. Stipelman, Daniel Stokols, Glen Morgan, and Sarah Gehlert. 2012. "A Four-Phase Model of Transdisciplinary Team-Based Research: Goals, Team Processes, and Strategies." *Translational Behavioral Medicine* 2(4):415–30.

Hansson, Stina and Merritt Polk. 2018. "Assessing the Impact of Transdisciplinary Research: The Usefulness of Relevance, Credibility, and Legitimacy for Understanding the Link between Process and Impact." *Research Evaluation* 27(2):132–44.

Hegger, Dries and Carel Dieperink. 2015. "Joint Knowledge Production for Climate Change Adaptation: What Is in It for Science?" *Ecology and Society* 20(4):1–13.

Hemlin, Sven. 1996. "Research on Research Evaluation." *Social Epistemology* 10(2):209–50.

Henze, Jennifer. 2021. "Zur Wissenschaftlichkeit Transdisziplinärer Forschung." *GAIA - Ecological Perspectives for Science and Society* 30(1):35–43.

Hilger, Annaliesa, Michael Rose, and Andreas Keil. 2021. "Beyond Practitioner and Researcher: 15 Roles Adopted by Actors in Transdisciplinary and Transformative Research Processes." *Sustainability Science* 16(6):2049–68.

Hirsch Hadorn, Gertrude, Christian Pohl, Holger Hoffmann-Riem, Susette Biber-Klemm, Urs

Wiesmann, Walter Grossenbacher-Mansuy, Elisabeth Zemp, and Dominique Joye. 2008. *Handbook of Transdisciplinary Research*. Cham: Springer International Publishing.

Hoffmann, Sabine, Julie Thompson Klein, and Christian Pohl. 2019. "Linking Transdisciplinary Research Projects with Science and Practice at Large: Introducing Insights from Knowledge Utilization." *Environmental Science & Policy* 102:36–42.

Hoffmann, Sabine, Christian Pohl, and Janet G. Hering. 2017. "Exploring Transdisciplinary Integration within a Large Research Program: Empirical Lessons from Four Thematic Synthesis Processes." *Research Policy* 46(3):678–92.

Ifejika Speranza, Chinwe, Felicia Olufunmilayo Akinyemi, David Baratoux, Jérôme Benveniste, Natalie Ceperley, Fatima Driouech, and Jörg Helmschrot. 2022. "Enhancing the Uptake of Earth Observation Products and Services in Africa Through a Multi-Level Transdisciplinary Approach." *Surveys in Geophysics* 44:7–41.

IPBES. 2019. Summary for policymakers of the global assessment report on biodiversity and ecosystem services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services edited by S. Díaz, J. Settele, E. S. Brondízio, H. T. Ngo, M. Guèze, J. Agard, A. Arneth, P. Balvanera, K. A. Brauman, S. H. M. Butchart, K. M. A. Chan, L. A. Garibaldi, K. Ichii, J. Liu, S. M. Subramanian, G. F. Midgley, P. Miloslavich, Z. Molnár, D. Obura, A. Pfaff, S. Polasky, A. Purvis, J. Razzaque, B. Reyers, R. Roy Chowdhury, Y. J. Shin, I. J. Visseren-Hamakers, K. J. Willis, and C. N. Zayas. IPBES secretariat, Bonn, Germany.

IPCC. 2022. Summary for Policymakers. H.-O. Pörtner, D.C. Roberts, E.S. Poloczanska, K. Mintenbeck, M. Tignor, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem (eds.). In: Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change edited by H.-O. Pörtner, D.C. Roberts, M. Tignor, E.S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, B. Rama. Cambridge University Press, Cambridge, UK and New York, NY, USA: 3–33.

IRP. 2019. Global Resources Outlook 2019: Natural Resources for the Future We Want. Oberle, B., Bringezu, S., Hatfield-Dodds, S., Hellweg, S., Schandl, H., Clement, J., and Cabernard, L., Che, N., Chen, D., Droz-Georget , H., Ekins, P., Fischer-Kowalski, M., Flörke, M., Frank, S., Froemelt , A., Geschke, A., Haupt , M., Havlik, P., Hüfner, R., Lenzen, M., Lieber, M., Liu, B., Lu, Y., Lutter, S., Mehr , J., Miatto, A., Newth, D., Oberschelp , C., Obersteiner, M., Pfister, S., Piccoli, E., Schaldach, R., Schüngel, J., Sonderegger, T., Sudheshwar, A., Tanikawa, H., van der Voet, E., Walker, C., West, J., Wang, Z., Zhu, B. A Report of the International Resource Panel. United Nations Environment Programme. Nairobi, Kenya.

Isgren, Ellinor, Anne Jerneck, and David O'Byrne. 2017. "Pluralism in Search of Sustainability: Ethics, Knowledge and Methdology in Sustainability Science." *Challenges in Sustainability* 5(1):2–6.

Jacobi, J., A. Llanque, S. Bieri, E. Birachi, R. Cochard, N. Depetris Chauvin, C. Diebold, R. Eschen, E. Frossard, T. Guillaume, S. Jaquet, F. Kämpfen, M. Kenis, D. I. Kiba, H. Komarudin, J. Madrazo, G. Manoli, S. M. Mukhovi, V. T. H. Nguyen, C. Pomalègni, S. Rüegger, F. Schneider, N. TriDung, P. von Groote, M. S. Winkler, J. G. Zaehringer, and C. Robledo-Abad. 2020. "Utilization of Research Knowledge in Sustainable Development Pathways: Insights from a Transdisciplinary Research-for-Development Programme." *Environmental Science & Policy* 103:21–29.

Jacobi, J., A. Llanque, S. M. Mukhovi, E. Birachi, P. von Groote, R. Eschen, I. Hilber-Schöb, D. I. Kiba, E. Frossard, and C. Robledo-Abad. 2022. "Transdisciplinary Co-Creation Increases the Utilization of Knowledge from Sustainable Development Research." *Environmental Science & Policy* 129:107–15.

Jaeger-Erben, Melanie, Johanna Kramm, Marco Sonnberger, Carolin Völker, Christian Albert, Antonia Graf, Kathleen Hermans, Steffen Lange, Tilman Santarius, Barbara Schröter, Stefanie Sievers-Glotzbach, and Janis Winzer. 2018. "Building Capacities for Transdisciplinary Research Challenges and Recommendations for Early-Career Researchers." *GAIA - Ecological Perspectives for Science and Society* 27(4):379–86.

Jahn, Thomas. 2008. "Transdisciplinarity in the Practice of Research (English Translation of German Paper)." Pp. 21–37 in *Transdisziplinäre Forschung. Integrative Forschungsprozesse verstehen und bewerten.* Vol. 37, edited by M. Bergmann and E. Schramm. Frankfurt, New York: Campus.

Jahn, Thomas, Matthias Bergmann, and Florian Keil. 2012. "Transdisciplinarity: Between Mainstreaming and Marginalization." *Ecological Economics* 79:1–10.

Jahn, Thomas and Florian Keil. 2015. "An Actor-Specific Guideline for Quality Assurance in Transdisciplinary Research." *Futures* 65:195–208.

Jantsch, Erich. 1970. "Inter- and Transdisciplinary University: A Systems Approach To Education and Innovation." *Policy Sciences* 1(1):403–28.

Jasanoff, Sheila. 1987. "Contested Boundaries in Policy-Relevant Science." *Social Studies of Science* 17(2):195–230.

Jasanoff, Sheila. 1998. *The Fifth Branch: Science Advisers as Policymakers*. Harvard: Harvard University Press.

Jasanoff, Sheila. 2003. "Technologies of Humility: Citizen Participation in Governing Science." *Minerva* 41(3):223–44.

Jasanoff, Sheila. 2014. "A Mirror for Science." *Public Understanding of Science* 23(1):21–26.

Jerneck, Anne, Lennart Olsson, Barry Ness, Stefan Anderberg, Matthias Baier, Eric Clark, Thomas Hickler, Alf Hornborg, Annica Kronsell, Eva Lövbrand, and Johannes Persson. 2011. "Structuring Sustainability Science." *Sustainability Science* 6(1):69–82.

Johnson, R. Burke, Anthony J. Onwuegbuzie, and Lisa A. Turner. 2007. "Towards a Definiton of Mixed Methods Research." *Journal of Mixed Methods Research* 1(2):112–33.

De Jong, Stefan P. L., Tjerk Wardenaar, and Edwin Horlings. 2016. "Exploring the Promises of Transdisciplinary Research: A Quantitative Study of Two Climate Research Programmes." *Research Policy* 45(7):1397–1409.

Kates, Robert W., William C. Clark, Robert Corell, J. Michael Hall, Carlo C. Jaeger, Ian Lowe, James J. Mccarthy, Hans Joachim Schellnhuber, Bert Bolin, Nancy M. Dickson, Sylvie Faucheux, Gilberto C. Calloprn, Arnulf Grübler, Brian Huntley, Jill Jäger, Narpat S. Jodha, Roger E. Kasperson, Akin Mabogunje, Pamela Matson, Harold Mooney, Berrien Moore Iii, Timothy O 'Riordan, and Uno Svedin. 2001. "Sustainability Science." *Science* 292:641–43.

Keitsch, Martina M. and Walter J. V Vermeulen. 2021. *Transdisciplinarity For Sustainability. Aligning Diverse Practices*. Oxon, New York: Routledge.

van Kerkhoff, Lorrae and Louis Lebel. 2006. "Linking Knowledge and Action for Sustainable Development." *Annual Review of Environment and Resources* 31(1):445–77.

Klein, Julie Thompson. 1990. *Interdisciplinarity - History, Theory, and Practice*. Detroit: Wayne State University Press.

Klein, Julie Thompson. 2004. “Prospects for Transdisciplinarity.” *Futures* 36(4):515–26.

Klein, Julie Thompson. 2014. “Discourses of Transdisciplinarity: Looking Back to the Future.” *Futures* 63:68–74.

Klein, Julie Thompson. 2021. *Beyond Interdisciplinarity: Boundary Work, Communication, and Collaboration*. Oxford: Oxford University Press.

Klein, Julie Thompson, Bianca Vienni Baptista, and Streck Danilo. 2022. “Introduction: Institutionalizing Interdisciplinarity and Transdisciplinarity: Collaboration across Cultures and Communities.” Pp. 1–10 in *Institutionalizing interdisciplinarity and transdisciplinarity: Cultures and communities, timeframes and spaces*, edited by B. V. Baptista and J. T. Klein. London: Routledge.

Klein, Julie Thompson, W. Grossenbacher-Mansuy, R. Häberli, A. Bill, R. W. Scholz, and M. Welti. 2001. *Transdisciplinarity: Joint Problem Solving among Science, Technology, and Society*. Basel, Boston, Berlin: Birkhäuser Verlag.

Kleinschmit, Daniela, Michael Böcher, and Lukas Giessen. 2009. “Forest Policy and Economics Discourse and Expertise in Forest and Environmental Governance — An Overview.” *Forest Policy and Economics* 11(5–6):309–12.

Knickel, Marina, Karlheinz Knickel, Francesca Galli, Damian Maye, and Johannes S. C. Wiskerke. 2019. “Towards a Reflexive Framework for Fostering Co-Learning and Improvement of Transdisciplinary Collaboration.” *Sustainability* 11(23):6–8.

Krainer, Verena and Larissa Winiwarter. 2016. “Die Universität Als Akteurin Der Transformativen Wissenschaft: Konsequenzen Für Die Messung Der Qualität Transdisziplinärer Forschung.” *GAIA - Ecological Perspectives for Science and Society* 25(2):110–16.

Kueffer, Christoph, Gertrude Hirsch Hadorn, Gabriele Bammer, Lorrae Van Kerkhoff, and Christian Pohl. 2007. “Towards a Publication Culture in Transdisciplinary Research.” *GAIA - Ecological Perspectives for Science and Society* 16(1):22–26.

Kueffer, Christoph, Flurina Schneider, and Urs Wiesmann. 2019. “Addressing Sustainability Challenges with a Broader Concept of Systems, Target, and Transformation Knowledge.” *GAIA - Ecological Perspectives for Science and Society* 28(4):386–88.

Kuhn, Thomas S. 2012. *The Structure of Scientific Revolutions*. Oxford: Oxford University Press.

Kullenberg, Christopher and Dick Kasperowski. 2016. “What Is Citizen Science? – A Scientometric Meta-Analysis.” *PLOS ONE* 11(1):e0147152.

Lam, David P. M., Maria E. Freund, Josefa Kny, Oskar Marg, Melanie Mbah, Lena Theiler, Matthias Bergmann, Bettina Brohmann, Daniel J. Lang, and Martina Schäfer. 2021. “Transdisciplinary Research: Towards an Integrative Perspective.” *GAIA - Ecological Perspectives for Science and Society* 30(4):243–49.

Lam, David P. M., Elvira Hinz, Daniel J. Lang, Maria Tengö, Henrik von Wehrden, and Berta Martín-López. 2020. “Indigenous and Local Knowledge in Sustainability Transformations Research: A Literature Review.” *Ecology and Society* 25(1):1–16.

Landry, Réjean, Nabil Amara, and Moktar Lamari. 2001. “Utilization of Social Science Research Knowledge in Canada.” *Research Policy* 30(2):333–49.

Lang, Daniel J., Arnim Wiek, Matthias Bergmann, Michael Stauffacher, Pim Martens, Peter Moll, Mark Swilling, and Christopher J. Thomas. 2012. "Transdisciplinary Research in Sustainability Science: Practice, Principles, and Challenges." *Sustainability Science* 7(SUPPL. 1):25–43.

Lawrence, Mark G., Stephen Williams, Patrizia Nanz, and Ortwin Renn. 2022. "Characteristics, Potentials, and Challenges of Transdisciplinary Research." *One Earth* 5(1):44–61.

Leach, Melissa, Ian Scoones, and Andy Stirling. 2010. *Sustainability Challenges in a Dynamic World.* London, Washintgon, D.C.: Earthscan.

Lemaitre, Frédéric and Xavier Le Roux. 2021. "Analysis of the Outputs of BiodivERsA Funded Projects: Projects Completed over 2014-2018." *BiodivERsA Report*.

Lentsch, J. and P. Weingart. 2011. *The Politics of Scientific Advice: Institutional Design for Quality Assurance*. Cambridge: Cambridge University Press.

Lövbrand, Eva. 2009. "Revisiting the Politics of Expertise in Light of the Kyoto Negotiations on Land Use Change and Forestry." *Forest Policy and Economics* 11(5–6):404–12.

Luederitz, Christopher, Niko Schäpke, Arnim Wiek, Daniel J. Lang, Matthias Bergmann, Joannette J. Bos, Sarah Burch, Anna Davies, James Evans, Ariane König, Megan A. Farrelly, Nigel Forrest, Niki Frantzeskaki, Robert B. Gibson, Braden Kay, Derk Loorbach, Kes McCormick, Oliver Parodi, Felix Rauschmayer, Uwe Schneidewind, Michael Stauffacher, Franziska Stelzer, Gregory Trencher, Johannes Venjakob, Philip J. Vergragt, Henrik von Wehrden, and Frances R. Westley. 2017. "Learning through Evaluation – A Tentative Evaluative Scheme for Sustainability Transition Experiments." *Journal of Cleaner Production* 169:61–76.

Lund, Dorthe H., Tove Enggrob Boon, and Iben Nathan. 2009. "Accountability of Experts in the Danish National Park Process." *Forest Policy and Economics* 11(5–6):437–45.

Lux, Alexandra, Martina Schäfer, Matthias Bergmann, Thomas Jahn, Oskar Marg, Emilia Nagy, Anna Christin Ransiek, and Lena Theiler. 2019. "Societal Effects of Transdisciplinary Sustainability Research – How Can They Be Strengthened during the Research Process?" *Environmental Science & Policy* 101:183–91.

Maasen, Sabine and Peter Weingart. 2005. "What's New in Scientific Advice to Politics?" Pp. 1–19 in *Democratization of Expertise?. Sociology of the Sciences Yearbook Vol. 24*, edited by S. Maasen and P. Weingart. Dodrecht: Springer.

Max-Neef, Manfred A. 2005. "Foundations of Transdisciplinary." *Ecological Economics* 53:5–16.

Merton, Robert K. 1942. "The Normative Structure of Science." Pp. 267–78 in *The sociology of science: Theoretical and empirical investigations*, edited by N. W. Storer. Chicago: University of Chicago Press.

Miller, Thaddeus R., Arnim Wiek, Daniel Sarewitz, John Robinson, Lennart Olsson, David Kriebel, and Derk Loorbach. 2014. "The Future of Sustainability Science: A Solutions-Oriented Research Agenda." *Sustainability Science* 9(2):239–46.

Misra, Shalini, Daniel Stokols, and Lulu Cheng. 2015. "The Transdisciplinary Orientation Scale : Factor Structure and Relation to the Integrative Quality and Scope of Scientific Publications." *Journal of Translational Medicine & Epidemiology* 3(2):1042.

Mitchell, Cynthia, Dana Cordell, and Dena Fam. 2015. "Beginning at the End: The Outcome Spaces Framework to Guide Purposive Transdisciplinary Research." *Futures* 65:86–96.

Mittelstraß, Jürgen. 1992. “Auf Dem Wege Zur Transdisziplinarität.” *GAIA - Ecological Perspectives for Science and Society* 1(5):250–250.

Mobjörk, Malin. 2010. “Consulting versus Participatory Transdisciplinarity: A Refined Classification of Transdisciplinary Research.” *Futures* 42(8):866–73.

Moewaka Barnes, Helen, Garth Harmsworth, Gail Tipa, Wendy Henwood, and Tim McCreanor. 2021. “Indigenous-Led Environmental Research in Aotearoa New Zealand: Beyond a Transdisciplinary Model for Best Practice, Empowerment and Action.” *AlterNative* 17(2):306–16.

Nagy, Emilia, Anna Ransiek, Martina Schäfer, Alexandra Lux, Matthias Bergmann, Thomas Jahn, Oskar Marg, and Lena Theiler. 2020. “Transfer as a Reciprocal Process: How to Foster Receptivity to Results of Transdisciplinary Research.” *Environmental Science & Policy* 104:148–60.

Newig, Jens and Oliver Fritsch. 2009. “The Case Survey Method and Applications in Political Science.” *American Political Science Assosciation 2009 Toronto Meeting Paper*.

Newig, Jens and Eva Kvarda. 2012. “Participation in Environmental Governance: Legitimate and Effective?” Pp. 29–45 in *Environmental Governance: The Challenge of Legitimacy and Effectiveness*, edited by K. Hogl, E. Kvarda, R. Nordbeck, and M. Pregernig. Cheltenham, Northampton: Edward Elgar Publishing Limited.

Newig, Jens and Michael Rose. 2020. “Cumulating Evidence in Environmental Governance, Policy and Planning Research: Towards a Research Reform Agenda.” *Journal of Environmental Policy & Planning Planning* 22(5):667–81.

Nicolescu, Basarab. 2014. “Methodology of Transdisciplinarity.” *World Futures* 70(3–4):186–99.

Niiniluoto, Ilkka. 1993. “The Aim and Structure of Applied Research.” *Erkenntnis* 38(1):1–21.

Norström, Albert V., Christopher Cvitanovic, Marie F. Löf, Simon West, Carina Wyborn, Patricia Balvanera, Angela T. Bednarek, Elena M. Bennett, Reinette Biggs, Ariane de Bremond, Bruce M. Campbell, Josep G. Canadell, Stephen R. Carpenter, Carl Folke, Elizabeth A. Fulton, Owen Gaffney, Stefan Gelcich, Jean Baptiste Jouffray, Melissa Leach, Martin Le Tissier, Berta Martín-López, Elena Louder, Marie France Loutre, Alison M. Meadow, Harini Nagendra, Davnah Payne, Garry D. Peterson, Belinda Reyers, Robert Scholes, Chinwe Ifejika Speranza, Marja Spierenburg, Mark Stafford-Smith, Maria Tengö, Sandra van der Hel, Ingrid van Putten, and Henrik Österblom. 2020. “Principles for Knowledge Co-Production in Sustainability Research.” *Nature Sustainability* 3(3):182–90.

Nowotny, Helga. 1999a. “The Need for Socially Robust Knowledge.” *TA-Datenbank-Nachrichten* 3(4):12–16.

Nowotny, Helga. 1999b. “The Place of People in Our Knowledge.” *European Review* 7(2):247–62.

Nowotny, Helga. 2003. “Democratising Expertise and Socially Robust Knowledge.” *Science and Public Policy* 30(3):151–56.

Nowotny, Helga, Peter Scott, and Michael Gibbons. 2001. *Re-Thinking Science: Knowledge and the Public in an Age of Uncertainty.* Cambridge: Polity Press.

Ojha, Hemant R., John Cameron, and Chetan Kumar. 2009. “Deliberation or Symbolic Violence? The Governance of Community Forestry in Nepal.” *Forest Policy and*

Economics 11(5–6):365–74.

Onwuegbuzie, Anthony J., Rebecca M. Bustamante, and Judith A. Nelson. 2010. “Mixed Research as a Tool for Developing Quantitative Instruments.” *Journal of Mixed Methods Research* 4(1):56–78.

Osborne, Peter. 2015. “Problematizing Disciplinarity, Transdisciplinary Problematics.” *Theory, Culture & Society* 32(6):3–35.

Ostrom, Elinor. 1996. “Crossing the Great Divide: Coproduction, Synergy, and Development.” *World Development* 24(6):1073–87.

Pärli, Rea, Manuel Fischer, and Eva Lieberherr. 2022. “What Are the Effects of Transdisciplinary Research Projects in the Global North and South? A Comparative Analysis.” *Current Research in Environmental Sustainability* 4:100180.

Pettibone, Lisa, Birgit Blättel-Mink, Bálint Balázs, Antonietta Di Giulio, Claudia Göbel, Katja Heubach, Diana Hummel, Johannes Lundershausen, Alexandra Lux, Thomas Potthast, Katrin Vohland, and Carina Wyborn. 2018. “Transdisciplinary Sustainability Research and Citizen Science: Options for Mutual Learning.” *GAIA - Ecological Perspectives for Science and Society* 27(2):222–25.

Phillipson, Jeremy, Philip Lowe, Amy Proctor, and Eric Ruto. 2012. “Stakeholder Engagement and Knowledge Exchange in Environmental Research.” *Journal of Environmental Management* 95(1):56–65.

Pielke Jr, Roger A. 2007. *The Honest Broker: Making Sense of Science in Policy and Politics*. Cambridge: Cambridge University Press.

Pohl, Christian, Julie Thompson Klein, Sabine Hoffmann, Cynthia Mitchell, and Dena Fam. 2021. “Conceptualising Transdisciplinary Integration as a Multidimensional Interactive Process.” *Environmental Science & Policy* 118:18–26.

Pohl, Christian, Bernhard Truffer, and Gertrude Hirsch Hadorn. 2017. “Addressing Wicked Problems through Transdisciplinary Research.” Pp. 319–31 in *The Oxford Handbook of Interdisciplinarity*, edited by R. Frodeman, J. T. Klein, and R. C. S. Pacheco. Oxford: Oxford University Press.

Polk, Merritt. 2015. “Transdisciplinary Co-Production: Designing and Testing a Transdisciplinary Research Framework for Societal Problem Solving.” *Futures* 65:110–22.

Popper, Karl. 2005. *The Logic of Scientific Discovery*. London, New York: Routledge Classics.

Pregernig, Michael. 2000. “Putting Science into Practice: The Diffusion of Scientific Knowledge Exemplified by the Austrian ‘Research Initiative Against Forest Decline.’” *Forest Policy and Economics* 1(2):165–76.

Pregernig, Michael. 2014. “Framings of Science-Policy Interactions and Their Discursive and Institutional Effects: Examples from Conservation and Environmental Policy.” *Biodiversity and Conservation* 23(14):3615–39.

Renn, Ortwin. 2021. “Transdisciplinarity: Synthesis towards a Modular Approach.” *Futures* 130:102744.

Rogga, Sebastian and Jana Zscheischler. 2021. “Opportunities, Balancing Acts, and Challenges - Doing PhDs in Transdisciplinary Research Projects.” *Environmental Science and Policy* 120(July 2020):138–44.

Rogga, Sebastian, Jana Zscheischler, and Nadin Gaasch. 2018. "How Much of the Real-World Laboratory Is Hidden in Current Transdisciplinary Research?" *GAIA - Ecological Perspectives for Science and Society* 27:18–22.

Rose, Michael and Katrin Maibaum. 2020. "Meeting the Challenge of (Co-) Designing Real-World Laboratories: Insights from the Well-Being Transformation Wuppertal Project." *GAIA-Ecological Perspectives for Science and Society* 29(3):154–60.

Rossman, Gretchen B. and Bruce L. Wilson. 1985. "Numbers and Words: Combining Quantitative and Qualitative Large-Scale Evaluation Study." *Evaluation Review* 9(5):627–43.

Ruppert-Winkel, Chantal, Robert Arlinghaus, Sonja Deppisch, Klaus Eisenack, Daniela Gottschlich, Bernd Hirschl, Bettina Matzdorf, Tanja Mölders, Martina Padmanabhan, Kirsten Selbmann, Rafael Ziegler, and Tobias Plieninger. 2015. "Characteristics, Emerging Needs, and Challenges of Transdisciplinary Sustainability Science: Experiences from the German Social-Ecological Research Program." *Ecology and Society* 20(3).

Sachs, Jeffrey D., Guido Schmidt-Traub, Mariana Mazzucato, Dirk Messner, Nebojsa Nakicenovic, and Johan Rockström. 2019. "Six Transformations to Achieve the Sustainable Development Goals." *Nature Sustainability* 2(9):805–14.

Sakao, Tomohiko and Sergio A. Brambila-Macias. 2018. "Do We Share an Understanding of Transdisciplinarity in Environmental Sustainability Research?" *Journal of Cleaner Production* 170:1399–1403.

Salomaa, A., R. Paloniemi, T. Hujala, S. Rantala, A. Arponen, and J. Niemela. 2016. "The Use of Knowledge in Evidence-Informed Voluntary Conservation of Finnish Forests." *Forest Policy and Economics* 73:90–98.

Schäfer, Martina, Matthias Bergmann, and Lena Theiler. 2021. "Systematizing Societal Effects of Transdisciplinary Research." *Research Evaluation* 30(4):484–99.

Schäfer, Martina, Alexandra Lux, and Matthias Bergmann. 2020. "Editorial to the Special Issue 'Transdisciplinary Sustainability Research – Linking Research Processes and Outputs to Societal Effects.'" *Environmental Science & Policy* 107:206–10.

Schaltegger, Stefan, Markus Beckmann, and Erik G. Hansen. 2013. "Transdisciplinarity in Corporate Sustainability: Mapping the Field." *Business Strategy and the Environment* 22(4):219–29.

Schäpke, Niko, Matthias Bergmann, Franziska Stelzer, and Daniel J. Lang. 2018. "Labs in the Real World: Advancing Transdisciplinary Research and Sustainability Transformation: Mapping the Field and Emerging Lines of Inquiry." *GAIA - Ecological Perspectives for Science and Society* 27(1):8–11.

Schäpke, Niko, Franziska Stelzer, Guido Caniglia, Matthias Bergmann, Matthias Wanner, Mandy Singer-Brodowski, Derk Loorbach, Per Olsson, Carolin Baedeker, and Daniel J. Lang. 2018. "Jointly Experimenting for Transformation? Shaping Real-World Laboratories by Comparing Them." *GAIA - Ecological Perspectives for Science and Society* 27(1):85–96.

Schneider, Flurina, Markus Giger, Nicole Harari, Stephanie Moser, Christoph Oberlack, Isabelle Providoli, Leonie Schmid, Theresa Tribaldos, and Anne Zimmermann. 2019. "Transdisciplinary Co-Production of Knowledge and Sustainability Transformations: Three Generic Mechanisms of Impact Generation." *Environmental Science & Policy* 102:26–35.

Schneider, Flurina, Aymara Llanque-Zonta, Onintsoa Ravaka Andriamihaja, R. Ntsiva N. Andriatsitohaina, Aung Myin Tun, Kiteme Boniface, Johanna Jacobi, Enrico Celio, Clara Léonie Diebold, Laby Patrick, Phokham Latthachack, Jorge Claudio Llopis, Lara Lundsgaard-Hansen, Peter Messerli, Stellah Mukhovi, Nwe Nwe Tun, Zo Hasina Rabemananjara, Bruno Salomon Ramamonjisoa, Sithong Thongmanivong, Thoumthone Vongvisouk, Daovorn Thongphanh, Win Myint, and Julie Gwendolin Zaehringer. 2022. "How Context Affects Transdisciplinary Research: Insights from Asia, Africa and Latin America." *Sustainability Science* 17(6):2331–45.

Scholz, Roland W., Daniel J. Lang, Arnim Wiek, Alexander I. Walter, and Michael Stauffacher. 2006. "Transdisciplinary Case Studies as a Means of Sustainability Learning: Historical Framework and Theory." *International Journal of Sustainability in Higher Education* 7(3):226–51.

Scholz, Roland W. and Gerald Steiner. 2015a. "The Real Type and Ideal Type of Transdisciplinary Processes: Part I—Theoretical Foundations." *Sustainability Science* 10(4):527–44.

Scholz, Roland W. and Gerald Steiner. 2015b. "Transdisciplinarity at the Crossroads." *Sustainability Science* 10(4):521–26.

Scholz, Roland W. and Olaf Tietje. 2002. *Embedded Case Study Methods*. Thousand Oaks: Sage Publications.

Sell, Kerstin, Franziska Hommes, Florian Fischer, and Laura Arnold. 2022. "Multi-, Inter-, and Transdisciplinarity within the Public Health Workforce: A Scoping Review to Assess Definitions and Applications of Concepts." *International Journal of Environmental Research and Public Health* 19(17):10902.

Spaapen, Jack and Leonie van Drooge. 2011. "Introducing 'Productive Interactions' in Social Impact Assessment." *Research Evaluation* 20(3):211–18.

Spangenberg, Joachim H. 2011. "Sustainability Science: A Review, an Analysis and Some Empirical Lessons." *Environmental Conservation* 38(03):275–87.

Stauffacher, Michael, Thomas Flüeler, Pius Krütli, and Roland W. Scholz. 2008. "Analytic and Dynamic Approach to Collaboration: A Transdisciplinary Case Study on Sustainable Landscape Development in a Swiss Prealpine Region." *Systemic Practice and Action Research* 21(6):409–22.

Steffek, Jens. 2009. "Discursive Legitimation in Environmental Governance." *Forest Policy and Economics* 11(5–6):313–18.

Steger, Cara, Julia A. Klein, Robin S. Reid, Sandra Lavorel, Catherine Tucker, Kelly A. Hopping, Rob Marchant, Tara Teel, Aida Cuni-Sanchez, Tsechoe Dorji, Greg Greenwood, Robert Huber, Karim Aly Kassam, David Kreuer, Anne Nolin, Aaron Russell, Julia L. Sharp, Mateja Šmid Hribar, Jessica P. R. Thorn, Gordon Grant, Mohammed Mahdi, Martha Moreno, and Daniel Waiswa. 2021. "Science with Society: Evidence-Based Guidance for Best Practices in Environmental Transdisciplinary Work." *Global Environmental Change* 68:102240.

Stokols, Daniel, Shalini Misra, Richard P. Moser, Kara L. Hall, and Brandie K. Taylor. 2008. "The Ecology of Team Science. Understanding Contextual Influences on Transdisciplinary Collaboration." *American Journal of Preventive Medicine* 35(2):S96–115.

Tebes, Jacob Kraemer and Nghi D. Thai. 2018. "Interdisciplinary Team Science and the Public: Steps toward a Participatory Team Science." *American Psychologist* 73(4):549–

62.

Tribaldos, Theresa, Christoph Oberlack, and Flurina Schneider. 2020. “Impact through Participatory Research Approaches: An Archetype Analysis.” *Ecology and Society* 25(3):1–25.

Vaughn, Lisa M. and Farrah Jacquez. 2020. “Participatory Research Methods – Choice Points in the Research Process.” *Journal of Participatory Research Methods* 1(1).

Vilsmaier, Ulli, Moritz Engbers, Philip Luthardt, Rina Marie Maas-Deipenbrock, Sebastian Wunderlich, and Roland W. Scholz. 2015. “Case-Based Mutual Learning Sessions: Knowledge Integration and Transfer in Transdisciplinary Processes.” *Sustainability Science* 10(4):563–80.

Walter, Alexander I., Sebastian Helgenberger, Arnim Wiek, and Roland W. Scholz. 2007. “Measuring Societal Effects of Transdisciplinary Research Projects: Design and Application of an Evaluation Method.” *Evaluation and Program Planning* 30(4):325–38.

Wamsler, Christine. 2017. “Stakeholder Involvement in Strategic Adaptation Planning: Transdisciplinarity and Co-Production at Stake?” *Environmental Science & Policy* 75:148–57.

Von Wehrden, Henrik, Christopher Luederitz, Julia Leventon, and Sally Russell. 2017. “Methodological Challenges in Sustainability Science: A Call for Method Plurality, Procedural Rigor and Longitudinal Research.” *Challenges in Sustainability* 5(1):35–42.

Weinberg, Alvin M. 1972. “Science and Trans-Science.” *Minerva* 10(2):209–22.

Weingart, Peter. 2010. “A Short History of Knowledge Formations.” Pp. 3–14 in *The Oxford Handbook of Interdisciplinarity*, edited by R. Frodeman, J. Thompson Klein, C. Mitcham, and J. B. Holbrook. Oxford: Oxford University Press.

Weingart, Peter and Justus Lentsch. 2008. *Wissen - Beraten - Entscheiden*. Weilerswist: Velbrück Wissenschaft.

Wickson, Fern and Anna L. Carew. 2014. “Quality Criteria and Indicators for Responsible Research and Innovation: Learning from Transdisciplinarity.” *Journal of Responsible Innovation* 1(3):254–73.

Wiek, Arnim, John Harlow, Rob Melnick, Sander van der Leeuw, Kensuke Fukushi, Kazuhiko Takeuchi, Francesca Farioli, Francis Yamba, Ann Blake, Chris Geiger, and Robert Kutter. 2015. “Sustainability Science in Action: A Review of the State of the Field through Case Studies on Disaster Recovery, Bioenergy, and Precautionary Purchasing.” *Sustainability Science* 10(1):17–31.

Wiek, Arnim, Sonia Talwar, Meg O’Shea, and John Robinson. 2014. “Toward a Methodological Scheme for Capturing Societal Effects of Participatory Sustainability Research.” *Research Evaluation* 23(2):117–32.

Williams, Stephen and John Robinson. 2020. “Measuring Sustainability: An Evaluation Framework for Sustainability Transition Experiments.” *Environmental Science & Policy* 103:58–66.

Wolf, Birge, Manfred Szerencsits, Hansjörg Gaus, Christoph E. Müller, and Jürgen Heb. 2014. “Developing a Documentation System for Evaluating the Societal Impact of Science.” *Procedia Computer Science* 33:289–96.

Wuelser, Gabriela, Carolina Adler, Thomas Breu, Gertrude Hirsch Hadorn, Urs Wiesmann, and Christian Pohl. 2021. “On Which Common Ground to Build? Transferable Knowledge across Cases in Transdisciplinary Sustainability Research.” *Sustainability*

Science 16(6):1891–1905.

Yin, Robert K. 2009. *Case Study Research: Design and Methods*. Thousand Oaks: Sage Publications.

Yin, Robert K. and Karen A. Heald. 1975. "Using the Case Survey Method to Analyze Policy Studies." *Administrative Science Quarterly* 20(3):371.

Zscheischler, Jana and Sebastian Rogga. 2015. "Transdisciplinarity in Land Use Science - A Review of Concepts, Empirical Findings and Current Practices." *Futures* 65:28–44.

Zscheischler, Jana, Sebastian Rogga, and Andrej Lange. 2018. "The Success of Transdisciplinary Research for Sustainable Land Use: Individual Perceptions and Assessments." *Sustainability Science* 13(4):1061–74.

Annex

Copyright notice

The research articles attached have been published in international peer-reviewed journals.

Article 1 [A1]: Jahn, Stephanie, Jens Newig, Daniel J. Lang, Judith Kahle, and Matthias Bergmann. 2022. Demarcating transdisciplinary research in sustainability science – Five clusters of research modes based on evidence from 59 research projects. *Sustainable Development*, 30(2), 343-357.

Article 2 [A2]: Newig, Jens, Stephanie Jahn, Daniel J. Lang, Judith Kahle, and Matthias Bergmann. 2019. Linking modes of research to their scientific and societal outcomes. Evidence from 81 sustainability-oriented research projects. *Environmental Science and Policy* 101, 147-155.

Article 3 [A3]: Juerges, Nataly and Stephanie Jahn. 2020. German forest management stakeholders at the science-society interface: Their views on problem definition, knowledge production and research utilization. *Forest Policy and Economics* 111, 102076.

Received: 1 October 2020 | Revised: 5 April 2021 | Accepted: 21 June 2021
DOI: 10.1002/sd.2278

SPECIAL ISSUE ARTICLE

Sustainable Development WILEY

Demarcating transdisciplinary research in sustainability science—Five clusters of research modes based on evidence from 59 research projects

Stephanie Jahn[1] | **Jens Newig**[1] | **Daniel J. Lang**[1] | **Judith Kahle**[1] | **Matthias Bergmann**[1,2]

[1]Faculty of Sustainability, Leuphana University Lüneburg, Lüneburg, Germany

[2]Research Unit Transdisciplinary Methods and Concepts, ISOE - Institute for Social-Ecological Research, Frankfurt am Main, Germany

Correspondence
Stephanie Jahn, Faculty of Sustainability, Leuphana University Lüneburg, Universitätsallee 1, 21335 Lüneburg, Germany.
Email: stephanie.jahn@leuphana.de

Funding information
German Research Foundation, Grant/Award Numbers: LA3024/1-1, NE1207/4-1

Abstract

The discourse revolving around "new modes of knowledge production"—particularly in sustainability-oriented research—seems to suggest a duality of transdisciplinary versus non-transdisciplinary research. Yet, in reality, a spectrum of transdisciplinary research modes may be expected. This article offers an empirically grounded distinction of five research modes, based on a cluster analysis of 59 completed sustainability-oriented research projects. Projects in one cluster approximate a transdisciplinary ideal type, while another cluster combines almost purely practice-oriented projects. Among the three remaining clusters with varying degrees of practitioner interaction, one cluster assembles projects with strictly academic research, while realizing substantial societal impact. Furthermore, our analyses indicate that the choice of research mode strongly depends on the funding context, with mission-oriented funding encouraging more collaborative modes. Overall, clusters with more practitioner interaction display stronger societal outputs and impacts at the cost of academic outputs and impacts. Beyond the demarcation of transdisciplinary research modes in sustainability science, our empirical analysis revealed three important tensions related to the theory and practice of this research approach: the duality of science and society (and scholars and practitioners); imbalances in the involvement and influence of different societal actor groups; and tensions between societal and academic outputs and impacts.

KEYWORDS
modes of research, research evaluation, societal impact, transdisciplinarity

1 | INTRODUCTION

Sustainability problems often transcend the boundaries of traditional scientific disciplines and call for collaboration between academia and actors from other societal domains (Jerneck et al., 2011; Kates et al., 2001; Leach et al., 2010). Concomitantly, the need for a new 'contract' between science and society has been declared, promoting new research modes that focus on real-world problems and that involve actors from outside academia (Gibbons, 1999; Lubchenco, 1998). The research community has been active in conceptualizing, observing, and advancing such research approaches in sustainability science, predominantly under the label of transdisciplinary research (see Brugnach &

Özerol, 2019; Horcea-Milcu et al., 2020; Keitsch & Vermeulen, 2021b; Renn, 2021 for recent overviews).

Notwithstanding this progress in conceptualizing transdisciplinarity, tensions have been observed between the theory of transdisciplinary research in sustainability science and on-the-ground experiences in actual research projects (Binder et al., 2015; Sakao & Brambila-Macias, 2018; Scholz & Steiner, 2015b; Vermeulen & Keitsch, 2021). Whereas a rich literature provides guidance for the design and evaluation of transdisciplinary projects (Belcher et al., 2016; Bergmann et al., 2012; Frodeman, 2017; Hirsch Hadorn et al., 2008), blueprints and ideal-typical models of transdisciplinary research require substantial adjustment to actual research questions, funding structures, or stakeholder fields. Hence, given the unique and individual circumstances of each project actual research practices vary in their expression of transdisciplinarity (Fernández González et al., 2021; Keitsch & Vermeulen, 2021a). Still, the discourse revolving around "new modes of knowledge production" – particularly in sustainability-oriented research—seems to imply a duality of transdisciplinary versus non-transdisciplinary research. Yet, in reality, a spectrum of more or less transdisciplinary research modes may be expected due to design decisions to navigate sustainability research within the boundaries of societal and scientific requirements. Empirical research on transdisciplinarity has illustrated the diversity of research approaches and revealed relationships between individual characteristics of research processes (Brandt et al., 2013; De Jong et al., 2016; Fernández González et al., 2021; Lux et al., 2019; Phillipson et al., 2012; Schneider, Giger, et al., 2019; Zscheischler et al., 2018). However, the literature is still lacking a robust and empirically grounded identification of different modes of research.

This paper aims to structure and synthesize experiences from 59 completed sustainability-oriented research projects[1] to identify distinguishable modes of research. In this way, we aim to inform and add nuance to existing theoretical frameworks on transdisciplinary research within sustainability science. By juxtaposing the different research modes, we additionally aim to explore both conceptual and methodological tensions that occur during the application of transdisciplinary approaches.

Below, we introduce our theoretical framework and hypotheses (Section 2), describe our cases, variables and methodological approach (Section 3), present the research modes that we identified in the 59 completed research projects (Section 4) and characterize the clusters in relation to our hypotheses and previous research (Section 5). Subsequently, we discuss the methodological and conceptual tensions that emerged from our empirical analysis (Section 6). We conclude with overall reflections on our research and an outlook for further research (Section 7).

2 | THEORETICAL FRAMEWORK AND HYPOTHESES

Our theoretical framework relates to previous works that define a normative model of an 'ideal-typical' transdisciplinary research process (Bergmann et al., 2005; Jahn, 2008; Lang et al., 2012). In this tradition, transdisciplinary research is defined as "a reflexive, integrative, method-driven scientific principle aiming at the solution or transition of societal problems and concurrently of related scientific problems by differentiating and integrating knowledge from various scientific and societal bodies of knowledge." (Lang et al., 2012, p. 26). Central to this understanding is the notion that transdisciplinary research integrates knowledge from academia and practice and, in turn, produces relevant and useful knowledge for both of these spheres (Bergmann et al., 2005; Jahn, 2008; Lang et al., 2012). This model of ideal-typical research processes assumes interdisciplinary as an integral part and precondition of transdisciplinarity. In our framework, we focus on the aspect of joint research practice between scholars and practitioners, following more recent debates around transdisciplinarity (Scholz & Steiner, 2015a, 2015b; Zscheischler & Rogga, 2015). We do, however, include interdisciplinary as an important context variable.

While models of ideal-typical transdisciplinary processes serve prescriptive purposes, our framework serves analytical and explanatory objectives (Figure 1): We generally pick up on the basic idea that transdisciplinary research processes seek to provide a shared space between societal and academic practice and to address societal problems in an integrative way (Lang et al., 2012). We expect that in the actual practice of sustainability science, a spectrum of different research modes occurs, which display varying combinations and degrees of the characteristics of a transdisciplinary ideal type (Hypothesis 1). Moreover, we assume that the occurrence of certain modes is shaped by the relevant funding context (H2), by constellations of interdisciplinary scholarly collaboration (H3) and by the spatial scale of the research project (H4). Furthermore, we assume that these modes of research play out differently in terms of actually producing societally and academic impacts (H5 and H6).

The recent discourse on transdisciplinarity is very much centered on solution orientation and efforts to detect, measure and enhance the societal impacts of transdisciplinary research (e.g. Belcher et al., 2016; Lux et al., 2019; Miller et al., 2014). Nevertheless, we explicitly acknowledge the dual role of transdisciplinary research to benefit practice and academia rather than mainly serving to make academic research more practice-relevant.

Our understanding of transdisciplinary research is one of close engagement between academic research and societal practice from outside academia. Hence, we do not relate to the strand of discourse that perceives transdisciplinarity essentially as an inner-academic practice, e.g. in the sense of a higher-level synthesis or transcendence of academic disciplines (for an overview, please see Thompson Klein, 2014).

2.1 | Characteristics of transdisciplinary research

In our framework, we refer to three fundamental dimensions of transdisciplinary research: (1) the orientation towards real-world problems, (2) the intensity of interactions with actors from outside academia,

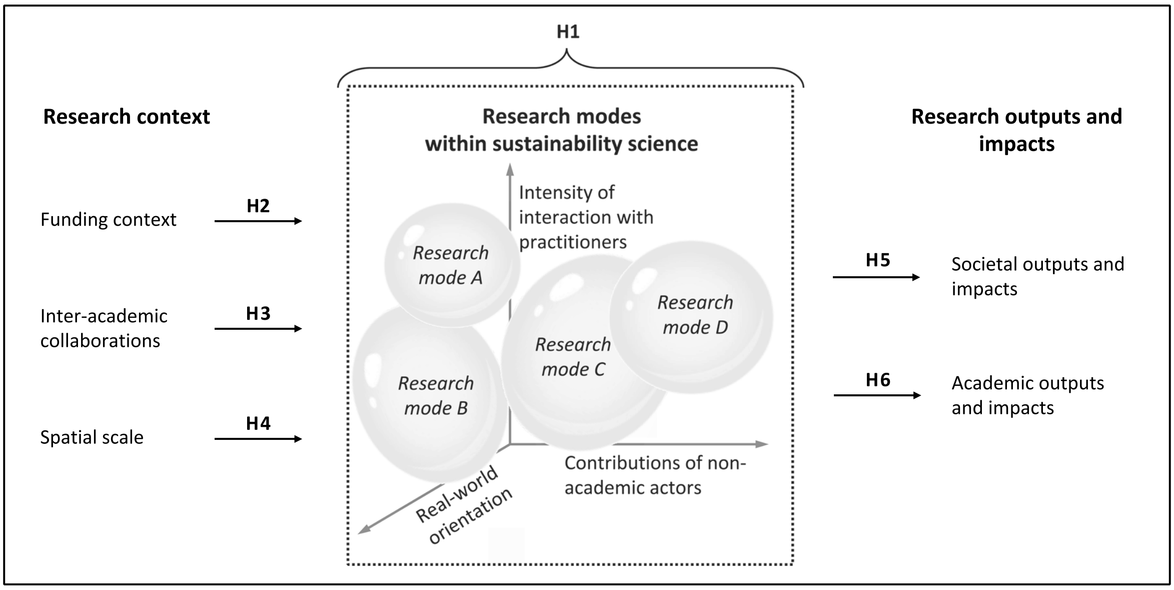

FIGURE 1 Theoretical framework and hypotheses. The figure provides a schematic overview over the relationships assumed in our hypotheses. As for Hypothesis 1, the 'bubbles' in the coordinate system are a simplified visualization of the assumption that projects cluster according to their specific combination of characteristics within the postulated three dimensions of ('more' or 'less') transdisciplinary research. The positioning of the 'bubbles' is exemplary and does not correspond to the actual positioning of the clusters of research modes that we identified empirically. A detailed overview over how the empirically identified clusters relate to the individual characteristics that are subsumed under the three dimensions is provided by Table 1 in Section 4. As indicated in Figure 1 Hypotheses 2, 3, and 4 relate to the research context that influences the expression of a certain research mode, while Hypotheses 5 and 6 refer to the characteristics of the outputs and impacts that are created by the different modes

and (3) the tangible contributions of the involved actors from outside academia. All characteristics subsumed under these dimensions are anchored in the broader discourse on transdisciplinary research and feature in the existing model presented in Lang et al., 2012[2] that was developed on the bases of the ideal-typical model of an transdisciplinary research process introduced by Jahn, 2008.

2.1.1 | Real-world orientation

A core feature of transdisciplinary research is that it departs from real-world problems (Häberli et al., 2001) and aims at producing knowledge that is applicable by political, economic and societal actors (Nowotny, 1999a)—rather than to pursue questions that are only relevant to the academic sphere alone.

2.1.2 | Intensity of interactions with actors from outside academia

Moreover, transdisciplinary research is fundamentally associated with interactions between academic scholars and practitioners (Jahn et al., 2012; Lang et al., 2012; Scholz & Steiner, 2015a; Thompson Klein et al., 2001). These transdisciplinary interactions can vary in their intensity (Lang et al., 2012; Stauffacher et al., 2008), ranging from rather selective, short-term collaborations to highly interactive project work, in which practitioners are engaged on equal footing, such as by leading (sub-) projects.

The intensity of interactions with actors from outside academia is also shaped by the degree of integration of these actors into the research process, what is strongly connected to the application of structured methods of knowledge integration (Bergmann et al., 2012; Defila & Di Giulio, 2015; Lux et al., 2019). Furthermore, the intensity of transdisciplinary interaction is defined by the practitioners' influence on the research project, for example whether practitioners are involved in project decisions (Bunders et al., 2010). Besides, transdisciplinarity is often associated with deliberation as a very intense form of interaction, for example, when heterogeneous (groups of) actors jointly develop solutions for sustainability problems (Bunders et al., 2010; Osborne, 2015; Scholz & Steiner, 2015a).

2.1.3 | Types of contributions of the involved actors from outside academia

The literature on transdisciplinarity discusses different types of contributions of the involved actors from outside academia. Jahn et al. (2012) and Lang et al. (2012) highlight the early involvement of practitioners in the phase of problem definition. In addition, Spangenberg (2011) mentions the joint definition of the research question.

The most pragmatic contribution of practitioners is the provision of knowledge on the field of action (Bunders et al., 2010; Enengel et al., 2012). Spaapen and van Drooge (2011) emphasize the joint product development or practitioners providing financial, material, or spatial resources as further pragmatic contributions. Furthermore, the literature highlights the importance for transdisciplinary research to listen to the needs and goals of practitioners, their underlying norms and values and therefore the conditions they see that need to change for a sustainable future (Isgren et al., 2017; Nowotny, 1999b; Spangenberg, 2011). Further important practitioner contributions include the assessment of the research results, and the dissemination of insights or products developed within the project and their practical implementation (Jahn et al., 2012; Lux et al., 2019; Nagy et al., 2020; Spaapen & van Drooge, 2011).

We assume that sustainability-oriented research projects vary in these characteristics of a transdisciplinary process and that it is therefore generally possible to distinguish specific combinations of these characteristics into clearly distinctive research modes (Hypothesis 1). The counter-hypothesis would be that the analyzed research projects distribute more or less evenly on a continuum.

H1. Distinct research modes can be distinguished as a combination of specific project-related characteristics.

2.2 | The context of transdisciplinary research

We assume that specific context conditions shape the possibilities of particular research modes.

2.2.1 | The funding context

Arguably, the employed research mode depends on the funding context. In Germany, the Federal Ministry for Research and Education (BMBF) funds mission-oriented research with specific thematic and partly methodological tenders. With the funding line *Social-ecological Research (SÖF)*, the BMBF has been funding sustainability-oriented projects since 1999, mostly requiring research to be transdisciplinary. In 2005, the BMBF launched the extensive and still ongoing funding program *Research for Sustainable Development (FONA)* to support the societal goal to foster sustainable development. The German Research Foundation (DFG) funds bottom-up research, with independent project proposals evaluated by peer review and panels structured along traditional disciplinary communities. Given these differences in funding structures, and in line with Balsiger (2005) Becker and Jahn (2006) and Schneider, Buser, et al., 2019, we assume the funding context to be decisive for research modes pursued by the studied projects.

H2. Research modes clearly discriminate between mission-oriented and bottom-up funding contexts.

2.2.2 | Inter-academic collaborations

As sustainability problems are not confined to individual academic disciplines, it has been argued that sustainability science requires not only the involvement of societal actors but also interdisciplinary collaborations (Hall et al., 2012; Jerneck et al., 2011; Lowe et al., 2013; Thompson Klein, 2004). Additionally, Gibbons et al. (1994) predicted an increasing heterogeneity of (academic) institutions and the emergence of new research institutions in the realm of a transition to new modes of knowledge production. Indeed, since the late 1970s, several independent not-for-profit research institutes have been founded in Germany outside the established research system, with the aim to develop concepts addressing social-ecological problems (Ecornet, 2020).[3] Accordingly, we assume that a research context in which 'traditional' academic institutions and their disciplinary structure prevail, hinders the realization of transdisciplinary research. Vice versa, we assume that transdisciplinarity requires a context of interactions between a variety of (inter-)disciplinary scholars and research institutions, which we subsume under the term 'inter-academic' collaborations.

H3. Inter-academic collaborations and research institutions outside the traditional academic structures enable and facilitate transdisciplinary research modes.

2.2.3 | Spatial scale

Moreover, it is assumed that a research project's spatial scale influences the possibilities for collaboration and involvement of extra-academic actors. Though sustainability problems are often described as global (Jerneck et al., 2011), the local level offers particular options to effectively address sustainability problems (Scholz et al., 2006; Thompson Klein, 2004; Wamsler, 2017).

H4. A local spatial context of a research project fosters the choice of a transdisciplinary research mode.

2.3 | Research outputs and impacts of transdisciplinary research

Transdisciplinary research is expected to deliver more practice-relevant and applicable results than non-transdisciplinary research, and to reach beyond the mere production of scientific knowledge (Bergmann et al., 2005; Funtowicz & Ravetz, 1993; Nowotny, 1999a). It is believed to benefit practitioners or society at large and to deliver solutions to sustainability problems (Hansson & Polk, 2018; Jahn et al., 2012; Lang et al., 2012; Wiek et al., 2014). Transdisciplinary research, being practice-oriented and collaborative, is expected to foster the practical usefulness of its research results and lead to societal impacts, for example in form of increased societal attention, changed attitudes, altered behavior or new regulations (Belcher et al., 2016; Hansson & Polk, 2018; Miller et al., 2014).

In turn, transdisciplinary projects may provide fewer resources for producing academic outputs, as compared with non-transdisciplinary projects. Therefore, we assume that transdisciplinary research gains less scientific outputs and impacts, as commonly measured by the number of scholarly publications and their respective citation (Hegger & Dieperink, 2015).

H5. Projects that display more characteristics of transdisciplinary research, show stronger societal outputs and impacts than projects that display less characteristics of transdisciplinary research.

H6. Projects that display more characteristics of transdisciplinary research, show lower scientific outputs and impacts as compared to projects that display less characteristics of transdisciplinary research.

3 | RESEARCH DESIGN

3.1 | Unit of analysis

The unit of analysis of our investigation is the research project as a "temporally, financially and staff-wise limited unit of activities in relation to one or more related research goals" (Newig et al., 2019, p. 149). As our population, we identified all sustainability-related research projects that (i) were funded between 2000 and 2012, either by the German Research Foundation (DFG) or by the German Federal Ministry of Education and Research (BMBF), and that (ii) combined at least two different disciplines, one of which had to be a social science. Projects were defined as sustainability-oriented if they used the terms 'sustainable' or 'sustainability' in the project title or the abstract, and if they did not use these terms merely in the sense of 'long-term'. We did not select projects depending on their (transdisciplinary) research mode. Instead, we aimed to study a broad spectrum of research modes. We found 156 research projects matching these criteria.[4] We contacted all 156 projects, and 59 provided sufficient data for our analysis.[5] This sample of 59 projects displays no significant differences compared to the basic population in terms of funding sum, funding duration and affiliation of projects to the two funding agencies and can therefore be regarded as representative for the population.

3.2 | Variables

The dataset consists of structured information from a systematic variable-based document analysis of project documents (research proposals, final reports, webpages, etc.) and questionnaires completed by principal investigators of projects, who had also been given the opportunity to validate project output lists assembled by us. A detailed list of variable definitions is available in the online supplementary of this paper. Here, we limit the description to the more complex variables:

We measured the real-world orientation of research projects via two variables; the degree to which a project's main research question is more oriented towards academic problems or towards real-world problems (*Research_question*), and the extent to which the production of societally applicable knowledge or results is described as a goal of the research project (*Goal_applied*).

The conceptual dimensions *Intensity of interactions with actors from outside academia* and *Type of practitioner contribution* are represented via a number of specific items that indicate whether an incident (such as for example long-term collaborations between scholars and practitioners or the contribution of practitioners to the formulation of the research question) has taken place in the project or not.

As societal productivity we define the number of publications in practitioner outlets, articles published in newspapers, press releases, newsletters, flyers, presentations and/or events for practitioners or the public, weighed relatively to their expected workload for project employees and controlled for the project's respective funding sum.

The index we use to measure the depth of the reported societal impacts of the research projects was derived from two open questions of our questionnaire, asking about (1) the societal results, the corresponding target audience, and (2) whether results were recognized or applied by practitioners and/or civil society. Structuring the respective answers in a qualitative content analysis, we developed the following impact scale: (1) recognition of project results outside academia; (2) discussion of project results; (3) putting project results to a practical test; (4) application of the generated results; and (5) long-term continuation of practices and networks. As multiple options could be chosen, the index comprises the sum of scores in all five impact categories.

As academic productivity, we understand all peer-reviewed scholarly articles, book chapters, anthologies, monographs, non-peer reviewed articles, working or discussion papers, conference proceedings as well as scientific presentations and events of a project, weighed relatively to their expected workload for project employees and controlled for its funding sum.

Our indicator for academic impact is based on the sum of citations of the project's academic publications within the first 5 years after publication, controlled for the respective funding sum.

3.3 | Data analysis

To answer Hypothesis 1 we used cluster analysis as an explorative statistical technique that uses differences or similarities between cases in a defined set of variables to group the cases into clusters. For doing so, above-mentioned characteristics of transdisciplinary research were operationalized through 23 distinct variables. Three of the variables are interval scaled, 20 of them are binary. The corresponding data were analyzed in a hierarchical cluster analysis applying Gower's general dissimilarity coefficient for mixed variables and Ward's method of agglomeration (Everitt et al., 2011) using STATA 15.0.

In order to test Hypotheses 2–6, differences between clusters in binary variables were tested with chi-squared test, differences in interval scaled variables were tested using non-parametric Mann–Whitney *U* test. More technical information on data structure and the statistical procedures is detailed in the online supplementary material.

4 | RESULTS I: RESEARCH MODES IN SUSTAINABILITY-ORIENTED RESEARCH

Graphical inspection of the cluster structure visualized in the dendrogram (Figure 2) suggests a five-cluster solution. The dendrogram shows that the most prominent differences occur between the two subsets of Clusters 1–3 and Clusters 4 and 5. In the following we provide detailed cluster descriptions along the lines of the clustering variables (see Table 1). Each cluster description is followed by a qualitative description of the case that is representative of the cluster.[6]

4.1 | Cluster 1—purely academic research

Projects in the smallest cluster, Cluster 1 ($n = 6$), show the lowest degree of application orientation compared to the other clusters. Furthermore, it is the only cluster whose research questions are predominantly academic. Moreover, Cluster 1 involves all cases with no practitioner involvement.

The exemplary Cluster 1 project aimed to develop a global economic model of the availability and use of a particular resource. Thereupon, the project aimed to simulate possible policy interventions to achieve a more efficient and sustainable global use of the resource. No actors from outside academia were actively involved.

4.2 | Cluster 2—practice consultation

Cluster 2 ($n = 9$) has a low application orientation, while its research questions, as compared with Cluster 1, are slightly more drawn towards real-world orientation. All cases in Cluster 2 describe a rather minimal form of interaction with actors from outside academia: The practitioners—from all societal sectors, with the highest share of private actors—were addressed as experts with the request for specific information or served as target audience for the project results. Consequently, the provision of knowledge receives the highest score of practitioner contributions in Cluster 2.

The project that is exemplary for Cluster 2 pursued an entirely academic research goal: to empirically investigate and internationally compare the influence of institutions on private companies in a specific sustainability-relevant area. Selected private companies were analyzed as case studies. These companies additionally served as a target group for the project outcomes and received a tailored report on the project's (interim) results once a year.

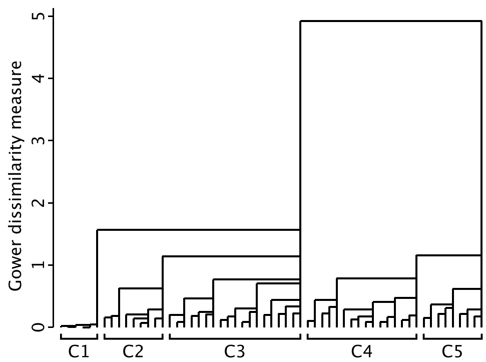

FIGURE 2 Dendrogram of the cluster structure of the 59 cases, based on the variables of the core characteristics of transdisciplinary research. The vertical lines in the dendrogram display the degree of dissimilarity between the created clusters applying Gower's general dissimilarity coefficient for mixed variables and Ward's method of agglomeration

4.3 | Cluster 3—selective practitioner involvement

Cluster 3 ($n = 19$) is the biggest cluster and is characterized by mostly short-term collaborations between practitioners and scholars. The research questions in this cluster are balanced between societal and academic interest, while this cluster is substantially application-oriented.

Three of the projects in this cluster (16%) involved practitioners in project decision-making. No project was initiated or led by practitioners, and practitioners were involved on equal footing in only one project. The highest levels of practitioner contributions are found with practitioners contributing knowledge and being active in the assessment and dissemination of the research results. One third of the projects applied structured methods of knowledge integration.

Practitioners from all societal sectors were involved, while governmental actors dominated (15 out of 19 projects involve actors from the governmental sector) and practitioners from the civic sector have their highest share in this cluster compared to the other clusters (nine projects, 47%).

The exemplary project for Cluster 3 aimed at analyzing the impacts of climate change on a specific agricultural sector, and developing mitigation strategies accordingly. Interactions with practitioners focused on one type of actor: farm managers, on whose land the field research was conducted. The farm managers attended project meetings or were approached through direct informal contacts. They were not involved in project decision-making, and no formal methods of knowledge integration were used, but they participated in the collaborative work on mitigation strategies.

4.4 | Cluster 4—ideal-typical transdisciplinary research

Compared to the previous clusters, Cluster 4 ($n = 16$) shows much more interaction with practitioners: 13 projects in this cluster (81%) are characterized by long-term and short-term collaboration, but all other forms of active interaction are also present in this cluster. Three quarters of the projects in this cluster involved practitioners in project decisions. Moreover, Cluster 4 has a higher orientation towards real-

TABLE 1 The five research mode clusters described with the variables used to cluster the cases. The core characteristics of transdisciplinary research (Hypothesis 1) ($n = 59$)

	Cluster 1 (n = 6) Purely academic research	**Cluster 2** (n = 9) Practice consultation	**Cluster 3** (n = 19) Selective practitioner involvement	**Cluster 4** (n = 16) Ideal-typical transdisciplinary research	**Cluster 5** (n = 9) Practice-oriented research
Variables	*Mean*	*Mean*	*Mean*	*Mean*	*Mean*
Characteristics of transdisciplinary sustainability research					
Research modes (H1)					
(1) Real-world orientation					
Research_question	-0.33	0.33	0.00	0.63	1.11
Goal_applied	0.83	0.89	1.90	2.56	2.56
(2) Intensity of interactions					
No_practitioners	1.00	0.00	0.00	0.00	0.00
Practitioners_consulting	0.00	1.00	0.05	0.00	0.00
Practitioners_shortterm	0.00	0.00	0.69	0.81	0.33
Practitioners_longterm	0.00	0.00	0.42	0.81	0.33
Practitioners_equal	0.00	0.00	0.05	0.19	0.89
Practitioners_inititating	0.00	0.00	0.00	0.13	0.33
Practitioners_PI	0.00	0.00	0.00	0.13	0.22
Knowledge_integration	0.00	0.00	0.32	0.50	0.22
Practitioners_decision	0.00	0.11	0.16	0.75	0.89
Practitioner_heterogeneity	0.00	1.67	1.90	2.06	1.56
> Governmental actors	0.00	0.33	0.79	0.69	0.56
> Private actors	0.00	0.56	0.47	0.69	0.89
> Civic actors	0.00	0.22	0.47	0.38	0.11
> Citizens	0.00	0.11	0.11	0.31	0.00
(3) Type of practitioner contributions					
Problem_definition	0.00	0.44	0.42	0.75	0.67
Research_question	0.00	0.11	0.00	0.19	0.78
Knowledge	0.00	0.67	0.63	0.94	0.89
Needs_goals	0.00	0.56	0.37	1.00	0.89
Norms_values	0.00	0.33	0.16	0.88	0.22
Product_development	0.00	0.00	0.00	0.31	0.78
Resources	0.00	0.00	0.11	0.31	0.56
Conditions_change	0.00	0.33	0.37	0.63	0.56
Assessment	0.00	0.44	0.74	0.88	1.00
Dissemination	0.00	0.33	0.63	0.94	1.00
Implementation	0.00	0.00	0.26	0.94	1.00

Notes: Outlined cells indicate that cluster is significantly different in this variable from all other clusters (statistical significance ≤*p* .05), differences between clusters in binary variables were tested with chi-squared test, differences in interval scaled variables were tested using non-parametric Mann–Whitney *U* test. The variables on the sectoral origin of the practitioners (governmental, private, civic, and citizens) entered the clustering indirectly aggregated in the variable 'Practitioner_heterogeneity'. The full analysis is displayed in Table A3.

world problems and a significantly higher application orientation than Clusters 1–3.

A notable characteristic of this cluster is its high share of projects in which practitioners were able to state their interests and beliefs. In all projects of this cluster the practitioners contributed by formulating their needs and goals, and in 14 projects (88%)—significantly more than in all other clusters—practitioners contributed by stating their norms and values. In addition, practitioners contributed in early project stages by (co-)defining the research problem (12 projects, 75%) and in the latest stages of the assessment, dissemination and implementation of the research results (14 projects, 88% to 15 projects, 94%).

Cluster 4 encompasses the highest share of projects that applied structured methods of knowledge integration (eight projects, 50%), which is recommended in an ideal-typical transdisciplinary process (Bergmann et al., 2012). Furthermore, this cluster displays the highest diversity of societal sectors involved, with relatively high percentages of each sector. Moreover, Cluster 4 is the one with the highest share of projects that involved citizens in their research activities (five projects, 31%). All in all, projects in this cluster come very close to the ideal-typical transdisciplinary research process described by Bergmann et al., 2005; Jahn, 2008; and Lang et al., 2012.

The exemplary Cluster 4 project aimed to identify risks of a new technology and to develop resulting risk assessment and communication strategies. Starting with contributions to problem identification, a large number of practitioners from a variety of institutions across all societal sectors and the public participated over the course of the project in long-term and/or short-term exchanges. The project was, for instance, accompanied by an advisory board composed of scholars and practitioners. Other practitioners participated in forums and thematic workshops. Scenario techniques, definition of key terms and the Delphi method were used as knowledge integration methods. The advisory board was involved in more minor decisions, such as which topics to involve in a survey.

4.5 | Cluster 5—practice-oriented research

In comparison, projects in Cluster 5 ($n = 9$) show the strongest orientation towards real-world problems in their research questions, while also exhibiting the same degree of application orientation as Cluster 4. Collaboration with practitioners from outside academia on equal footing is reported for as much as eight (89%) of the Cluster 5 projects. In addition, eight of the cluster's projects (89%) involved practitioners in project decisions. Moreover, Cluster 5 projects show the highest shares of practitioners initiating or leading a (sub-)project as a principal investigator. Taken together, Cluster 5 is characterized by projects with the most practitioner influence.

In terms of practitioner contributions, Cluster 5 is characterized by projects with the highest share of practitioners contributing to product development (seven projects, 78%). Cluster 5 has the significantly highest amount of practitioners being involved in the crucial phase of formulation of the research question. In all Cluster 5 projects, practitioners contributed to assessing research results or products, their dissemination and implementation. All Cluster 5 projects but one involved practitioners from the private sector with less involvement of civic and governmental actors and no citizen involvement.

The project that is exemplary for Cluster 5 had the practical aim to develop a financial product for the sustainable management of a particular resource. This financial product was to be tested in a specific municipality. Researchers and actors from the administration of this municipality acquired the project with a joint proposal and realized the project as partners on equal footing. Thus, the municipal administration was involved in all project decisions. Further practitioners included actors from an engineering office and the private sector. This set of actors met regularly, continuously discussed the current state of work, and jointly developed the final project report. Moreover, workshops were conducted for external stakeholders.

5 | RESULTS II: RELATIONSHIPS BETWEEN RESEARCH MODE, CONTEXT, OUTPUT AND IMPACT

Below, we characterize the five identified clusters in relation to the six hypotheses formulated above. To facilitate interpretation, Table 2 highlights important features and differences between the five research mode clusters.

5.1 | Research modes within sustainability science (Hypothesis 1)

In Hypothesis 1, we assumed that it is possible to demarcate distinct research modes within a range of different research projects. Our empirical results generally confirm this hypothesis. The cluster analysis with the set of variables that we defined as core characteristics of transdisciplinary research revealed five clusters that encompass substantially different research modes: from *purely academic research* (Cluster 1) to wholly *practice-oriented research* (Cluster 5). Cluster 4 aligns most closely with what has been described as an ideal type of transdisciplinary research (Jahn, 2008; Lang et al., 2012; Scholz & Steiner, 2015a). Moreover, we can connect our findings to Mobjörk's (2010) distinction between "consulting" and "participatory" transdisciplinarity. While the former refers to limited involvement mainly as information inputs from the practice side, the latter characterizes research with substantial involvement and knowledge co-production. The dendrogram's main dividing line (Figure 2) separates Clusters 1–3 from Clusters 4 and 5. Clusters 2 and 3 encompass projects applying a problem focus, but limited interactions with practitioners, focused on responding and reacting to the research in alignment with the features of Mobjörk's 'consulting transdisciplinarity' category 'Participatory transdisciplinarity', where practitioners are fully included in the knowledge production process, can be related to Cluster 4 and, by this standard, also to Cluster 5. Furthermore, in this our results show similarities to the division between 'classical consultative research' and 'practical problem-solving and co-innovation' as defined by a cluster analysis of transdisciplinary research in agroecology by Fernández González et al. (2021).

Although we can generally relate our findings to conceptualizations and typologies in the literature, our cluster structure further extends these by offering a more detailed differentiation into five empirically based research modes within sustainability science. The entirety of the clusters we identified could be interpreted as a spectrum ranging from purely academic to practice-oriented research, as the intensity of practitioner influence on the research process augments with increasing cluster number.

However, this directionality of practitioner influence does not imply that the degree of transdisciplinarity increases from Cluster 1–5. Notably, projects in Cluster 5 share characteristics of a transdisciplinary process, but Cluster 5 shows a specific pattern that strongly aligns with concepts of applied research. The notion of 'applied research' is associated with research conducted in design with stakeholders from outside academia (mainly from business and industry), who usually determine the research topics (Grunwald, 2015). Applied research often sees problem frames tailored to specific actor groups (Mobjörk, 2010), and its core aim is to develop "new products, methods, and means of production" (Niiniluoto, 1993, p. 2). Cluster 5 displays high scores of practitioner influence and more practitioner contributions to product development than the other clusters. Moreover, the involved actors from outside academia are less heterogeneous, mostly involving private business but no citizens.

Taken together, our empirically informed cluster structure demarcates "ideal-type" transdisciplinarity (Cluster 4) as an approach that is not equal to pure practitioner-led research but characterized by an intensive, yet balanced involvement of practitioners, acknowledging their needs and goals as well as their norms and values (Isgren

TABLE 2 Differences between the five research mode clusters in context and in societal and academic output and impact (reduced variable set, $n = 59$)

	Cluster 1 (n = 6) Purely academic research	**Cluster 2** (n = 9) Practice consultation	**Cluster 3** (n = 19) Selective practitioner involvement	**Cluster 4** (n = 16) Ideal-typical transdisciplinary research	**Cluster 5** (n = 9) Practice-oriented research
Variables	*Mean*	*Mean*	*Mean*	*Mean*	*Mean*
Research Context					
Funding context (H2)					
BMBF (mission-oriented)	0.67	0.22	0.74	0.94	1.00
DFG (bottom-up)	0.33	0.78	0.26	0.06	0.00
Interacademic Collaborations (H3)					
Institutional_heterogeneity	1.83	1.11	1.84	2.00	1.88
Share_university	0.61	0.93	0.74	0.58	0.58
Share_non-profit_research	0.16	0.07	0.07	0.19	0.20
Share_private_research	0.00	0.00	0.09	0.18	0.12
Disciplinary_heterogeneity	2.00	1.44	2.53	2.88	2.67
Share_interdisciplinary	0.21	0.12	0.22	0.26	0.22
Spatial perspective (H4)					
Perspective_international	0.67	0.11	0.16	0.06	0.00
Perspective_regional	0.17	0.56	0.37	0.31	0.11
Perspective_municipal	0.17	0.00	0.21	0.19	0.33
Outputs and Impacts					
Societal outputs and impacts (H5)					
Societal_productivity	16.367	2.51	9.64	19.77	13.87
Societal_impact	1.837	0.67	1.05	4.13	3.56
Academic outputs and impacts (H6)					
Academic_productivity	91.397	69.03	74.71	42.09	23.89
Academic_impact	1330.71	267.32	249.49	68.18	15.19

Notes: Outlined cells indicate that the cluster is significantly different in this variable from all other clusters (statistical significance ≤p .05), differences between clusters in binary variables were tested with chi-squared test, differences in interval scaled variables were tested using non-parametric Mann–Whitney U test. The values for Clusters 2 and 3 in the variables Disciplinary_heterogeneity and Share_interdisciplinary are softened to indicate missing values (see Table A5). Table 2 displays a reduced set of variables. The full analysis is displayed in the Tables A4–A7.

et al., 2017). Furthermore, in transdisciplinary research an intention to mediate between different actors or actor groups (Scholz & Steiner, 2015a)—as indicated by higher practitioner heterogeneity—is flanked by the application of structured methods of knowledge integration (Bergmann et al., 2012).

5.2 | The context of transdisciplinary research (Hypotheses 2–4)

With perspective to Hypothesis 2, we observe a nuanced pattern. Clearly, our five research modes align with funding programs. The highly interactive Clusters 4 and 5 are almost exclusively populated by BMBF-funded projects, responding to the ministry's mission oriented tenders. Cluster 2 (*practice consultation)* is dominated by DFG individual grants, while Cluster 4 only includes one DFG-funded project. This may suggest that the DFG funding criteria do not particularly attract transdisciplinary research approaches. We may even speculate that DFG funding decision-making favors more traditional research modes. Conversely, *purely academic research* Cluster 1 shows a mix of BMBF- and DFG-funded projects that roughly represents the distribution in the whole sample (see Table A2), showing that both bottom-up and mission-oriented research can have a strong academic orientation with high impacts into the academic community.

Projects from the social-ecological research funding line of the BMBF are most present in Cluster 4. This was to be expected, as the tenders in this funding line specifically demand a transdisciplinary research mode. The fact that projects from the social-ecological research funding line also appear in other clusters (especially in Cluster 1) might indicate that the spectrum of transdisciplinarity as demanded by the BMBF is not limited to 'ideal-type' transdisciplinary processes. Moreover, we observe that projects of the sustainable land management funding line are strongly represented in Cluster 5, which reflects the fact that tenders of this funding line require real-world impacts (here: the reduction of human land use) as the primary goal and selection criterion for research projects. What kind of research mode is promoted (and pursued by projects) thus not only seems to depend on the funding institution but to a good degree also on the individual funding lines and their specific demands.[7]

Regarding Hypothesis 3 on the co-occurrence of transdisciplinary collaborations and inter-academic collaborations, our findings are less straightforward. In terms of inter-institutional collaborations, we observe that Clusters 1, 3, 4, and 5 operate on a very similar level, with a slightly higher institutional heterogeneity for the *transdisciplinary ideal type* Cluster 4. *Practitioner consultation* Cluster 2 displays the lowest value, which is likely due to the large share of individual DFG-funded projects, which usually encompass only one research unit at a university. Moreover, we can observe that university involvement decreases with the intensity of interaction from Cluster 2 to Cluster 5, with more interactive Clusters 4 and 5 displaying slightly higher shares of not-for-profit and private research institutes.

The data quality of the variables describing the disciplinary set up is unfortunately limited. Thus, the results have to be interpreted with caution, excluding Cluster 2 and 3 from our interpretation. Nonetheless, we can see that the *transdisciplinary ideal type* Cluster 4 displays the highest share of interdisciplinary scholars working on the projects and the highest rate of scholars from different disciplinary backgrounds. Together, these results provide some support for our Hypothesis 3.

Concerning Hypothesis 4, it appears that the level of projects on the smallest spatial scale (municipal scale) increases with the degree of practitioner orientation from Cluster 2 to 5. Nevertheless, the pattern is more nuanced as there is a directly opposite relationship for the regional scale, in which the *practice consultation* Cluster 2 is on top (five of the projects out of nine projects (56%) in this cluster operate on the regional level). Noteworthy is the high share of projects referring to the international scale in the *purely academic* Cluster 1 (four out of six projects (67%) and significantly higher than all other clusters), which again aligns with Hypothesis 4.

5.3 | Societal and academic outputs and impacts (Hypotheses 5 and 6)

In Hypothesis 5—informed strongly by conceptual research on transdisciplinarity – we assumed that projects that display more characteristics of an ideal-typical transdisciplinary research process lead to stronger societal outputs and impacts.

Previous comparative empirical research on transdisciplinary research found that less intensive ("consulting") transdisciplinarity showed stronger societal effects than more intensive science-practice interactions (De Jong et al., 2016; Phillipson et al., 2012). Our study, which considers the whole range of research modes from purely academic to practitioner-led, adds to this body of literature by generally confirming Hypothesis 5. We find that ideal-typical transdisciplinary research (Cluster 4) shows the strongest societal impacts, followed by the *practice-oriented* Cluster 5. Both Clusters have substantially higher scores in societal impact than the less interactive Clusters 1, 2, and 3. These differences are statistically significant for Clusters 2 and 3.

Interestingly, the *purely academic research* Cluster 1, in which no project has any practitioner interaction, shows a relatively high societal impact as compared to the slightly more practice-oriented Clusters 2 and 3. We suggest two possible explanations: On the one hand, one could assume that purely academic research on sustainability subjects with strong academic outputs proves to be societally relevant, even without practitioner interaction. On the other hand, the fact that Cluster 1 also displays high levels of practice-relevant output in form of publications and events for practitioners (societal productivity second highest of all clusters) suggests that targeted dissemination and communication into the practitioner field fosters societal impact.

In Hypothesis 6, we assumed that more transdisciplinary research modes would be less productive and impactful in academic terms. While earlier research found inconclusive evidence on the link between collaboration with practitioners and scientific publications and citations (Hegger & Dieperink, 2015), our empirical results generally confirm Hypothesis 6: With increasing practice-orientation and practitioner involvement, academic outputs and impacts clearly decline (from Cluster 1 to 5). The *classical academic research* Cluster 1 displays the highest level of academic productivity in terms of scientific publications, and academic impact, measured by citations (both relative to the project's respective funding sum). Specifically, the *practice-oriented* Cluster 5 displays the lowest level of academic impact by far, significantly different from all other clusters. However, as discussed above in Hypothesis 1, projects in Cluster 5 are not the most transdisciplinary ones.

Overall, we find an inverse relationship between societal and academic outputs and impacts for at least Clusters 2–5, proposing a trade-off between activities and effects in these two spheres, which confirms our earlier regression analyses on 81 research projects (Newig et al., 2019) as well as similar results by Zscheischler et al. (2018). This might question the capacity of transdisciplinary research purported by the ideal-typical transdisciplinary research process in the tradition of Bergmann et al. (2005), Jahn (2008) and Lang et al. (2012) to ideally produce both valuable contributions for science and society.

6 | CHALLENGES OF DOING TRANSDISCIPLINARY RESEARCH: TENSIONS DERIVED FROM THE ANALYSIS

While engaging with the demarcation of transdisciplinary research in sustainability science, our empirical analysis revealed three important tensions and challenges related to the theory and practice of transdisciplinary research for sustainability transformations.

6.1 | The assumed dualism of science and society in transdisciplinary research

Approaches to transdisciplinarity often imply a conceptual dualism of science and society, which has also been imminent in our own study. In the wording of our questions and indicators, we used 'science' and 'society' largely as complementary and often mutually exclusive categories to which we assigned project activities, outputs and impacts. Hence, we also assigned actors to either science or society according to their main professional attribution. With regards to the related differentiation of 'scientists' and 'practitioners', our questionnaire had been directed at the principal investigator, who in the vast majority of projects had been an academic scholar. Yet, especially the structure of our *practice-oriented* research mode represented by Cluster 5 raises the question about who should be defined as a 'researcher'. In this cluster, practitioners are participating on equal footing or even as principal investigators of (sub-)projects. Thus, we would encourage future research to move beyond the dualistic perspective of scientists versus practitioners, and pay due attention to the nuances of individual actors engaged in transdisciplinary sustainability research, such as research-related consulting firms, or researchers interested in entrepreneurial action. An approach to overcome the scholar-practitioner dualism is by focusing on the various roles that one actor can take on in transdisciplinary research (Bulten et al., 2021; Wittmayer & Schäpke, 2014), rather than seeing actors only through their (formally) attributed status. In particular, future research ought to consider the various roles that practitioners fill in transdisciplinary research, such as advocate, researcher or consultant.

6.2 | Imbalances in the involvement and influence of different societal actor groups

Empirically, we find a tension between practitioners' societal sector and their respective intensity of involvement and influence. In *practice-oriented* Cluster 5 we observe a high share of projects in which practitioners are joining on equal footing, who are involved in the definition of the research question and influence the research process. At the same time, this cluster has the highest share of private sector actors and the lowest share of civic actors (e.g., from NGOs or associations, etc.) and involves no citizens. Conversely, the *selective practitioner involvement* Cluster 3 shows the highest share of actors from the civic sector of all clusters, while practitioners in this cluster join the project activities predominantly on short-term and have little influence on project decisions.

On the one hand, this observation might be attributed to the fact that there are different objectives for stakeholder involvement in transdisciplinary research (Schmidt et al., 2020), so we may not expect homogenous patterns of involvement, due to actor specific capacities, resources, and legitimacy for sustainability problem solving. On the other hand, it could also be the case that not all actors have equal capacities and resources to take part in transdisciplinary research projects (Fritz & Binder, 2020; Osinski, 2021). If the latter were to account for the comparatively less intensive involvement of civil society actors in the studied projects, the conclusion would be to explicitly design transdisciplinary processes that anticipate such factors and provide, for example, for sufficient resources to activate and compensate 'less-advantaged' actor groups.

6.3 | Tensions between societal and academic outputs and impacts

Comparing the five identified clusters in their societal and academic outputs and impacts, the question arises whether sustainability-oriented research can fulfill the expectations to contribute to both scientific and societal progress. We found that *purely academic research* (Cluster 1) can be societally relevant, but also that highly interactive research modes (Cluster 4 and Cluster 5) have significantly less impact in the academic sphere. Certainly, the model of the transdisciplinary ideal-type does not claim that transdisciplinary research *equally* contributes to both realms, and it is disputable whether societal and scientific outputs and impacts should be weighed against each other. A potential explanation for our findings is indicated by the work of Zscheischler et al. (2018): Asking a larger number of scholars for what defines a successful transdisciplinary research project, they found a "significant imbalance within the science-practice outcome equilibrium with an orientation leaning toward the practice side of TDR (transdisciplinary research)" (ibid., p. 1070).

This issue also highlights the dilemma of the double expectations researchers face in transdisciplinarity between producing knowledge according to scientific standards and to team up with societal actors in joint problem solving (Bulten et al., 2021). Limited resources require prioritization and decisions on which activities to attribute time and attention to—which seem currently often at the cost of contributions to the academic community. Moreover, Bulten et al. (ibid.) discovered a general insecurity among scholars of how to report knowledge generated in transdisciplinary research in a scientific way. This also implies the question if there is a need to adjust or further develop the prevalent scientific publication structures and processes as well as the related reward and tenure systems to accommodate the requested new modes of research.

Given the importance of academic performance for academic careers, we would like to encourage further research to investigate how academic contributions of transdisciplinary research can be enhanced to mitigate the trade-off we observed. In our analysis we used rather conventional indicators, as we measured academic performance with the number of scientific publications and their respective citations. Despite the growing critique of the extensive use of these indicators in research governance, these are still the units in which academic success is most commonly assessed (Mingers & Leydesdorff, 2015). Since the general current discourse on transdisciplinarity is often centered on societal impacts (e.g. Lux et al., 2019; Palmer et al., 2020; Schneider, Giger, et al., 2019; Williams & Robinson, 2020), we would like to initiate a discussion about how to navigate transdisciplinary sustainability research in this field of tension between societal and scientific demands. We aimed to identify clusters of research modes, but it does turn out to be important to additionally take a close look at individual projects that stand out and actively balance societal and scientific aims (for examples of such projects, see Newig et al. (2019) on a qualitative analysis of a subsample of our data).

7 | CONCLUSION AND OUTLOOK

Based on the tensions between transdisciplinary ideal types and on-the-ground experiences in actual research projects, our cluster analysis of 59 completed sustainability-oriented research projects yielded five distinct research modes. These add nuances to existing theoretical conceptualizations and empirical studies that mostly focus on ideal types and best practices of transdisciplinary research. At the same time, we also find that the diversity of research characteristics does not randomly or evenly populate the space of possible research modes but clusters around five relatively distinct modes. These clusters deepen the understanding of actual research modes and their respective societal and academic outputs and impacts. By comparing ideal-typical transdisciplinary research Cluster 4 and practice-oriented Cluster 5, we were able to contribute to the conceptual demarcation of transdisciplinary and applied research. We would like to encourage forthcoming research to add up on this demarcation effort in analyzing further projects. Moreover, our analysis underscores the importance of research policy and of funding programs in advancing and shaping transdisciplinarity and related modes of knowledge production.

In the wider reflection of the identified research modes, we were able to identify three tensions across the different ways of doing transdisciplinary research. Based on these tensions, we would like to propose for future research to apply the concept of roles to actors and practitioners to overcome the conceptual 'researcher–practitioner' dualism in transdisciplinary research. Moreover, we would like to emphasize the need to systematically approach differences in the capacities, resources and legitimacy of specific actor groups to avoid potential imbalances in involvement patterns. Last, we would like to encourage further research to increase efforts to mitigate the trade-off between societal and academic impacts and outputs that we observed in our empirical data.

Our study was limited to the German research context. We therefore would like to raise attention to the need for comparative large-n studies of sustainability-related research modes on an international scale. This is of special importance, as the majority of comparable empirical studies we found to contextualize our findings were conducted in a Central European context (e.g. Bulten et al., 2021; De Jong et al., 2016; Fritz & Binder, 2020; Phillipson et al., 2012; Zscheischler et al., 2018).

As a practical contribution to research planning and management, our typology and the relationship between research modes and their impacts could help setting the methodological priorities along the trajectories of the societal and scholarly aims of future research. Moreover, our findings may support funding agencies in setting up effective research programs, combining different modes of research to reach multi-dimensional impacts in society and academia to push sustainable development forward.

ACKNOWLEDGMENTS

The authors would like to thank the members of our advisory group, Antonietta di Giulio, Rico Defila, Michael Pregernig, Arnim Wiek and Michael Stauffacher, for their constructive and valuable feedback in early stages of this research; Nicolas W. Jager for reviewing the clustering procedure; the German Research Foundation for providing the funding for the research project Modes of sustainability-related research in comparison (MONA): Modes of research and their impact on scientific and societal project outcomes under grant numbers NE1207/4-1 to Jens Newig and LA3024/1-1 to Daniel J. Lang; staff from the German Research Foundation and the German Federal Ministry of Education and Research for their support in preparing the data collection; project heads, researchers and practitioners involved in the investigated sustainability-oriented research projects for providing us with project documents, as well as for participating in a survey and semi-structured interviews; our student assistants Marie Josefine Hintz, Marie Weiß, Marion Blome, Sophia Schönig, Maria Brück, Silke Bölts, Alina Langkau, Franziska Steinbrügge, Jakob Wondra and Inga Melchior for their long-term and outstanding support with regard to data collection and data editing in preparation for this article.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

ENDNOTES

[1] We rely on data gathered on 59 interdisciplinary sustainability-oriented research projects funded by the two largest German funding institutions, the German Federal Ministry of Research and Education (BMBF) and the German Research Foundation (DFG).

[2] The Lang et al. (2012) model is based on a broad literature review and integrates numerous earlier approaches to conceptualize transdisciplinary research processes (ibid.). Furthermore, it has been taken up by various research endeavors (internationally, but with a majority from the global north, especially central Europe) (e.g. Avelino, 2017; Norström et al., 2020; Sachs et al., 2019; Schaltegger et al., 2017).

[3] Eight of these independent not-for-profit research institutes are organized in the ECORNET-network, but there do exist several more.

[4] The used data is a subset of the larger dataset of the research project 'Modes of sustainability-related research in comparison (MONA): Modes of research and their impact on scientific and societal project outcomes'. In Newig et al. (2019) which is based on the same dataset, this number has been erroneously been stated as 141 for the n of the basic population.

[5] In Newig et al. (2019) the analysis was based on variables that were available for 81 cases.

[6] The case displaying the least overall deviation from the cluster mean in the clustering variables has been identified as being most representative for the cluster.

[7] The results on the BMBF funding lines are displayed in Table A4 in the online supplementary.

REFERENCES

Avelino, F. (2017). Power in sustainability transitions: Analysing power and (dis)empowerment in transformative change towards sustainability. *Environmental Policy and Governance*, *27*(6), 505–520. https://doi.org/10.1002/eet.1777

Balsiger, P. W. (2005). *Transdisciplinarität: systematisch-vergleichende Untersuchung disziplinübergreifender Wissenschaftspraxis*. Wilhelmm Fink Verlag.

Becker, E., & Jahn, T. (2006). In E. Becker & T. Jahn (Eds.), *Soziale Ökologie. Grundzüge einer Wissenschaft von den gesellschaftlichen Naturverhältnissen*. Campus.

Belcher, B. M., Rasmussen, K. E., Kemshaw, M. R., & Zornes, D. A. (2016). Defining and assessing research quality in a transdisciplinary context. *Research Evaluation*, *25*(1), 1–17. https://doi.org/10.1093/reseval/rvv025

Bergmann, M., Brohmann, B., Hoffmann, E., Loibl, M. C., Rehaag, R., Schramm, E., & Voss, J.-P. (2005). Quality criteria of transdisciplinary research. A guide for the formative evaluation of research projects. Institut Fuer Sozial-Oekologische Forschung (ISOE), *76*. http://www.isoe.de

Bergmann, M., Knobloch, T., Krohn, W., Pohl, C., & Schramm, E. (2012). *Methods for transdisciplinary research. A primer for practice*. Campus Verlag.

Binder, C. R., Absenger-Helmli, I., & Schilling, T. (2015). The reality of transdisciplinarity: A framework-based self-reflection from science and practice leaders. *Sustainability Science*, *10*(4), 545–562. https://doi.org/10.1007/s11625-015-0328-2

Brandt, P., Ernst, A., Gralla, F., Luederitz, C., Lang, D. J., Newig, J., Reinert, F., Abson, D. J., & Von Wehrden, H. (2013). A review of transdisciplinary research in sustainability science. *Ecological Economics*, *92*, 1–15. https://doi.org/10.1016/j.ecolecon.2013.04.008

Brugnach, M., & Özerol, G. (2019). Knowledge co-production and transdisciplinarity: Opening Pandora's box. *Water (Switzerland)*, *11*(10), 1–6. https://doi.org/10.3390/w11101997

Bulten, E., Hessels, L. K., Hordijk, M., & Segrave, A. J. (2021). Conflicting roles of researchers in sustainability transitions: Balancing action and reflection. *Sustainability Science*, *0123456789*, 1269–1283. https://doi.org/10.1007/s11625-021-00938-7

Bunders, J. F. G., Broerse, J. E. W., Keil, F., Pohl, C., Scholz, R. W., & Zweekhorst, M. B. M. (2010). How can transdisciplinary research contribute to knowledge democracy? In R. J. in't Veld, (ed). *Knowledge democracy: Consequences for science, politics, and media* (pp. 125–152). Springer. https://doi.org/10.1007/978-3-642-11381-9_11

De Jong, S. P. L., Wardenaar, T., & Horlings, E. (2016). Exploring the promises of transdisciplinary research: A quantitative study of two climate research programmes. *Research Policy*, *45*(7), 1397–1409. https://doi.org/10.1016/j.respol.2016.04.008

Defila, R., & Di Giulio, A. (2015). Integrating knowledge: Challenges raised by the "Inventory of Synthesis". *Futures*, *65*, 123–135. https://doi.org/10.1016/j.futures.2014.10.013

Ecornet. (2020). Profile of the Ecological Research Network. https://www.ecornet.eu/en/profile.html

Enengel, B., Muhar, A., Penker, M., Freyer, B., Drlik, S., & Ritter, F. (2012). Co-production of knowledge in transdisciplinary doctoral theses on landscape development-an analysis of actor roles and knowledge types in different research phases. *Landscape and Urban Planning*, *105*(1–2), 106–117. https://doi.org/10.1016/j.landurbplan.2011.12.004

Everitt, B. S., Landau, S., Leese, M., & Stahl, D. (2011). *Cluster analysis (5th Edition)*. John Wiley & Sons, Ltd.

Fernández González, C., Ollivier, G., & Bellon, S. (2021). Transdisciplinarity in agroecology: Practices and perspectives in Europe. *Agroecology and Sustainable Food Systems*, *45*(4), 523–550. https://doi.org/10.1080/21683565.2020.1842285

Fritz, L., & Binder, C. R. (2020). Whose knowledge, whose values? An empirical analysis of power in transdisciplinary sustainability research. *European Journal of Futures Research*, *8*(1), 1–21. https://doi.org/10.1186/s40309-020-0161-4

Frodeman, R. (2017). In R. Frodeman (Ed.), *The Oxford handbook of Interdisciplinarity* (Vol. 1). Oxford University Press. https://doi.org/10.1093/oxfordhb/9780198733522.001.0001

Funtowicz, S. O., & Ravetz, J. R. (1993). Science for the post-normal age. *Futures*, *25*(7), 739–755. https://doi.org/10.1016/0016-3287(93)90022-L

Gibbons, M., Limoges, C., Nowotny, H., Schwartzman, S., Scott, P., & Trow, M. (1994). *The new production of knowledge. The dynamics of science and research in contemporary societies*. London: Sage Publications Ltd.

Gibbons, M. (1999). Science's new social contract with society. *Nature*, *402*(1), C81–C84. https://doi.org/10.1038/35011576

Grunwald, A. (2015). Transformative science—A new order in academia? *Gaia*, *24*(1), 17–20. https://doi.org/10.14512/gaia.24.1.5

Häberli, R., Bill, A., Thompson Klein, J., Scholz, R. W., & Welti, M. (2001). Summary and synthesis. In J. Thompson Klein, W. Grossenbacher-Mansuy, R. Häberli, A. Bill, R. W. Scholz, & M. Welti (Eds.), *Transdisciplinarity: Joint problem solving among science, technology, and society*. Basel.

Hall, K. L., Vogel, A. L., Stipelman, B. A., Stokols, D., Morgan, G., & Gehlert, S. (2012). A four-phase model of transdisciplinary team-based research: Goals, team processes, and strategies. *Translational Behavioral Medicine*, *2*(4), 415–430. https://doi.org/10.1007/s13142-012-0167-y

Hansson, S., & Polk, M. (2018). Assessing the impact of transdisciplinary research: The usefulness of relevance, credibility, and legitimacy for understanding the link between process and impact. *Research Evaluation*, *27*(2), 132–144. https://doi.org/10.1093/reseval/rvy004

Hegger, D., & Dieperink, C. (2015). Joint knowledge production for climate change adaptation: What is in it for science? *Ecology and Society*, *20*(4), 1–13. https://doi.org/10.5751/ES-07929-200401

Hirsch Hadorn, G., Pohl, C., Hoffmann-Riem, H., Biber-Klemm, S., Wiesmann, U., Grossenbacher-Mansuy, W., Joye, D., Pohl, C., Wiesmann, U., Zemp, E. (Eds.) (2008). *Handbook of transdisciplinary research*. Springer. https://doi.org/10.1007/978-1-4020-6699-3

Horcea-Milcu, A.-I., Martín-López, B., Lam, D. P. M., & Lang, D. J. (2020). Research pathways to foster transformation: Linking sustainability science and social-ecological systems research. *Ecology and Society*, *25*(1), art13. https://doi.org/10.5751/ES-11332-250113

Isgren, E., Jerneck, A., & O'Byrne, D. (2017). Pluralism in search of sustainability: Ethics, knowledge and Methdology in sustainability science. *Challenges in Sustainability*, *5*(1), 2–6. https://doi.org/10.12924/cis2017.05010002

Jahn, T. (2008). Transdisciplinarity in the practice of research (English translation of German paper). In *Transdisziplinäre Forschung. Integrative Forschungsprozesse verstehen und bewerten* (Vol. 37, pp. 21–37). Campus.

Jahn, T., Bergmann, M., & Keil, F. (2012). Transdisciplinarity: Between mainstreaming and marginalization. *Ecological Economics*, *79*, 1–10. https://doi.org/10.1016/j.ecolecon.2012.04.017

Jerneck, A., Olsson, L., Ness, B., Anderberg, S., Baier, M., Clark, E., Hickler, T., Hornborg, A., Kronsell, A., Lövbrand, E., & Persson, J. (2011). Structuring sustainability science. *Sustainability Science*, *6*(1), 69–82. https://doi.org/10.1007/s11625-010-0117-x

Kates, R. W., Clark, W. C., Corell, R., Hall, J. M., Jaeger, C. C., Lowe, I., McCarthy, J. J., Schellnhuber, H. J., Bolin, B., Dickson, N. M., Faucheux, S., Gallopin, G. C., Grübler, A., Huntley, B., Jäger, J., Jodha, N. S., Kasperson, R. E., Mabogunje, A., Matson, P., … Svedin, U. (2001). Sustainability science. *Science*, *292*(5517), 641–642.

Keitsch, M. M., & Vermeulen, W. J. V. (2021a). Aligning diverse practices of transdisciplinarity for sustainability. In M. M. Keitsch & W. J. V. Vermeulen (Eds.), *Transdisciplinarity for sustainability, aligning diverse practices* (pp. 1–5). Routledge.

Keitsch, M. M., & Vermeulen, W. J. V. (2021b). *Transdisciplinarity for sustainability. Aligning diverse practices*. Routledge.

Lang, D. J., Wiek, A., Bergmann, M., Stauffacher, M., Martens, P., Moll, P., Swilling, M., & Thomas, C. J. (2012). Transdisciplinary research in sustainability science: Practice, principles, and challenges. *Sustainability Science*, *7*(1), 25–43. https://doi.org/10.1007/s11625-011-0149-x

Leach, M., Scoones, I., & Stirling, A. (2010). Sustainability challenges in a dynamic world. In *Dynamic sustainabilities: Technology environment social justice* (1st ed.). Earthscan. https://doi.org/10.4324/9781849775069

Lowe, P., Phillipson, J., & Wilkinson, K. (2013). Why social scientists should engage with natural scientists. *Contemporary Social Science*, *8*(2013), 207–222. https://doi.org/10.1080/21582041.2013.769617

Lubchenco, J. (1998). Entering the century of the environment: A new social contract for science. *Science*, *279*(5350), 491–497. https://doi.org/10.1126/science.279.5350.491

Lux, A., Schäfer, M., Bergmann, M., Jahn, T., Marg, O., Nagy, E., Ransiek, A. C., & Theiler, L. (2019). Societal effects of transdisciplinary sustainability research—How can they be strengthened during the research process? *Environmental Science and Policy*, *101*, 183–191. https://doi.org/10.1016/j.envsci.2019.08.012

Miller, T. R., Wiek, A., Sarewitz, D., Robinson, J., Olsson, L., Kriebel, D., & Loorbach, D. (2014). The future of sustainability science: A solutions-oriented research agenda. *Sustainability Science*, *9*(2), 239–246. https://doi.org/10.1007/s11625-013-0224-6

Mingers, J., & Leydesdorff, L. (2015). A review of theory and practice in Scientometrics. *European Journal of Operational Research*, *246*, 1–19.

Mobjörk, M. (2010). Consulting versus participatory transdisciplinarity: A refined classification of transdisciplinary research. *Futures*, *42*(8), 866–873. https://doi.org/10.1016/j.futures.2010.03.003

Nagy, E., Ransiek, A., Schäfer, M., Lux, A., Bergmann, M., Jahn, T., Marg, O., & Theiler, L. (2020). Transfer as a reciprocal process: How to foster receptivity to results of transdisciplinary research. *Environmental Science and Policy*, *104*(2019), 148–160. https://doi.org/10.1016/j.envsci.2019.11.007

Newig, J., Jahn, S., Lang, D. J., Kahle, J., & Bergmann, M. (2019). Linking modes of research to their scientific and societal outcomes. Evidence from 81 sustainability-oriented research projects. *Environmental Science and Policy*, *101*, 147–155. https://doi.org/10.1016/j.envsci.2019.08.008

Niiniluoto, I. (1993). The aim and structure of applied research. *Erkenntnis*, *38*(1), 1–21.

Norström, A. V., Cvitanovic, C., Löf, M. F., West, S., Wyborn, C., Balvanera, P., Bednarek, A. T., Bennett, E. M., Biggs, R., de Bremond, A., Campbell, B. M., Canadell, J. G., Carpenter, S. R., Folke, C., Fulton, E. A., Gaffney, O., Gelcich, S., Jouffray, J.-B., Leach, M., … Österblom, H. (2020). Principles for knowledge co-production in sustainability research. *Nature Sustainability*, *3*(3), 182–190. https://doi.org/10.1038/s41893-019-0448-2

Nowotny, H. (1999a). The need for socially robust knowledge. *TA-Datenbank-Nachrichten*, *3*(4), 12–16. http://www.itas.fzk.de/deu/tadn/tadn993/nowo99a.pdf

Nowotny, H. (1999b). The place of people in our knowledge. *European Review*, *7*(2), 247–262. https://doi.org/10.1017/S1062798700004026

Osborne, P. (2015). Problematizing disciplinarity, transdisciplinary problematics. *Theory, Culture & Society*, *32*(6), 3–35. https://doi.org/10.1177/0263276415592245

Osinski, A. (2021). Towards a critical sustainability science? Participation of disadvantaged actors and power relations in transdisciplinary research. *Sustainability (Switzerland)*, *13*(3), 1–21. https://doi.org/10.3390/su13031266

Palmer, H., Polk, M., Simon, D., & Hansson, S. (2020). Evaluative and enabling infrastructures: Supporting the ability of urban co-production processes to contribute to societal change. *Urban Transformations*, *2*(1), 1–14. https://doi.org/10.1186/s42854-020-00010-0

Phillipson, J., Lowe, P., Proctor, A., & Ruto, E. (2012). Stakeholder engagement and knowledge exchange in environmental research. *Journal of Environmental Management*, *95*(1), 56–65. https://doi.org/10.1016/j.jenvman.2011.10.005

Renn, O. (2021). Transdisciplinarity: Synthesis towards a modular approach. *Futures*, *130*, 102744. https://doi.org/10.1016/j.futures.2021.102744

Sachs, J. D., Schmidt-Traub, G., Mazzucato, M., Messner, D., Nakicenovic, N., & Rockström, J. (2019). Six transformations to achieve the sustainable development goals. *Nature Sustainability*, *2*(9), 805–814. https://doi.org/10.1038/s41893-019-0352-9

Sakao, T., & Brambila-Macias, S. A. (2018). Do we share an understanding of transdisciplinarity in environmental sustainability research? *Journal of Cleaner Production*, *170*, 1399–1403. https://doi.org/10.1016/j.jclepro.2017.09.226

Schaltegger, S., Etxeberria, I. Á., & Ortas, E. (2017). Innovating corporate accounting and reporting for sustainability—Attributes and challenges. *Sustainable Development*, *25*(2), 113–122. https://doi.org/10.1002/sd.1666

Schmidt, L., Falk, T., Siegmund-Schultze, M., & Spangenberg, J. H. (2020). The objectives of stakeholder involvement in Transdisciplinary research. A conceptual framework for a reflective and reflexive Practise. *Ecological Economics*, *176*, 106751. https://doi.org/10.1016/j.ecolecon.2020.106751

Schneider, F., Buser, T., Keller, R., Tribaldos, T., & Rist, S. (2019). Research funding programmes aiming for societal transformations: Ten key stages. *Science and Public Policy*, *46*(3), 463–478. https://doi.org/10.1093/scipol/scy074

Schneider, F., Giger, M., Harari, N., Moser, S., Oberlack, C., Providoli, I., Schmid, L., Tribaldos, T., & Zimmermann, A. (2019). Transdisciplinary co-production of knowledge and sustainability transformations: Three generic mechanisms of impact generation. *Environmental Science and Policy*, *102*, 26–35. https://doi.org/10.1016/j.envsci.2019.08.017

Scholz, R. W., Lang, D. J., Wiek, A., Walter, A. I., & Stauffacher, M. (2006). Transdisciplinary case studies as a means of sustainability learning: Historical framework and theory. *International Journal of Sustainability in Higher Education*, *7*(3), 226–251. https://doi.org/10.1108/14676370610677829

Scholz, R. W., & Steiner, G. (2015a). The real type and ideal type of transdisciplinary processes: Part I—Theoretical foundations. *Sustainability Science*, *10*(4), 527–544. https://doi.org/10.1007/s11625-015-0326-4

Scholz, R. W., & Steiner, G. (2015b). Transdisciplinarity at the crossroads. *Sustainability Science*, *10*(4), 521–526. https://doi.org/10.1007/s11625-015-0338-0

Spaapen, J., & van Drooge, L. (2011). Introducing "productive interactions" in social impact assessment. *Research Evaluation*, *20*(3), 211–218. https://doi.org/10.3152/095820211X12941371876742

Spangenberg, J. H. (2011). Sustainability science: A review, an analysis and some empirical lessons. *Environmental Conservation*, *38*(3), 275–287. https://doi.org/10.1017/S0376892911000270

Stauffacher, M., Flüeler, T., Krütli, P., & Scholz, R. W. (2008). Analytic and dynamic approach to collaboration: A transdisciplinary case study on sustainable landscape development in a swiss prealpine region. *Systemic Practice and Action Research*, *21*(6), 409–422. https://doi.org/10.1007/s11213-008-9107-7

Thompson Klein, J. (2004). Prospects for transdisciplinarity. *Futures*, *36*(4), 515–526. https://doi.org/10.1016/j.futures.2003.10.007

Thompson Klein, J. (2014). Discourses of transdisciplinarity: Looking back to the future. *Futures*, *63*, 68–74. https://doi.org/10.1016/j.futures.2015.01.003

Thompson Klein, J., Grossenbacher-Mansuy, W., Häberli, R., Bill, A., Scholz, R. W., & Welti, M. (2001). *Transdisciplinarity: Joint problem solving among science, technology, and society*. Birkhäuser Verlag.

Vermeulen, W. J. V., & Keitsch, M. M. (2021). Challenges of transdisciplinary research collaboration for sustainable development. In W. J. V. Vermeulen & M. M. Keitsch (Eds.), *Transdisciplinarity for sustainability. Aligning diverse practices* (pp. 200–207). Routledge.

Wamsler, C. (2017). Stakeholder involvement in strategic adaptation planning: Transdisciplinarity and co-production at stake? *Environmental Science and Policy*, *75*, 148–157. https://doi.org/10.1016/j.envsci.2017.03.016

Wiek, A., Talwar, S., O'Shea, M., & Robinson, J. (2014). Toward a methodological scheme for capturing societal effects of participatory sustainability research. *Research Evaluation*, *23*(2), 117–132. https://doi.org/10.1093/reseval/rvt031

Williams, S., & Robinson, J. (2020). Measuring sustainability: An evaluation framework for sustainability transition experiments. *Environmental Science & Policy*, *103*, 58–66.

Wittmayer, J. M., & Schäpke, N. (2014). Action, research and participation: Roles of researchers in sustainability transitions. *Sustainability Science*, *9*(4), 483–496. https://doi.org/10.1007/s11625-014-0258-4

Zscheischler, J., & Rogga, S. (2015). Transdisciplinarity in land use science - A review of concepts, empirical findings and current practices. *Futures*, *65*, 28–44. https://doi.org/10.1016/j.futures.2014.11.005

Zscheischler, J., Rogga, S., & Lange, A. (2018). The success of transdisciplinary research for sustainable land use: Individual perceptions and assessments. *Sustainability Science*, *13*(4), 1061–1074. https://doi.org/10.1007/s11625-018-0556-3

SUPPORTING INFORMATION

Additional supporting information may be found in the online version of the article at the publisher's website.

How to cite this article: Jahn, S., Newig, J., Lang, D. J., Kahle, J., & Bergmann, M. (2022). Demarcating transdisciplinary research in sustainability science—Five clusters of research modes based on evidence from 59 research projects. *Sustainable Development*, *30*(2), 343–357. https://doi.org/10.1002/sd.2278

Supporting information to the paper
"Demarcating transdisciplinary research in sustainability science – Five clusters of research modes with evidence from 59 research projects"

This file contains additional details on the clustering procedure (section 1), a descriptive list of variables (section 2) and detailed results tables (section 3) including all tested differences in variables for the five clusters.

1 Additional details on the clustering procedure:

The values of the metric variables were replaced by their ranks to receive variables on the same scale (standardization) as recommended by (Wedel & Kamakura, 2012) and (Everitt, Landau, Leese, & Stahl, 2011). Even though the number of variables used for clustering is rather high in relation to our sample size, no principal component analysis (PCA) was conducted to reduce the number of variables "because PCA discards relevant distance information and several arbitrary decisions are involved. The tandem combination of principal component analysis and clustering is not justifiable on theoretical or empirical grounds" (Wedel and Kamakura, 2012, p. 58).
To determine the number of clusters in the data, the test of Mojena (Milligan & Cooper, 1985) was performed, which indicates a 2-cluster solution. Graphical inspection of the dendrogram (Graph 1 in the paper) confirms the 2-cluster solution, but offers also options of a four and five cluster solution. Prioritizing the explorative potential of the cluster analysis over statistical determination, cluster solutions of up to 7 clusters were determined and analyzed content wise for conceptual differences in the clustering variables. The 5-cluster solution presented in this paper has been selected due to most explorative gain. The stability of the chosen 5-cluster solution has been examined by comparing 50 random 90%-subsamples of the cases with the solution of the 59 cases receiving a Rand Index of 0,65. Alternative cluster-solutions are described in Table A1. The 5-cluster solution is presented in detail in Table A3 in this online supplementary to make our interpretation comprehensible and to be retraced by our readers.
As the vast majority of our interval-scaled variables is not normally distributed, the non-parametric Wilcoxon-Mann-Whitney U test has been used to indicate significant differences in variables between the single clusters for our interval-scaled variables. The Chi^2-test was used to test for significant differences between binary variables. Also due to the non-normal distribution of most of our interval-scaled variables, we have to forego a test of overall signif-

icant differences between all clusters with an ANOVA, as normality is a precondition of ANOVA (Backhaus, Erichson, Plinke, & Weiber, 2016).

Table A1: Comparison of clustering results with lower and higher numbers of clusters

<table>
<tr><th>2-cluster solution</th><th>3-cluster solution</th><th>4-cluster solution</th><th>5-cluster solution</th><th>6-cluster solution</th><th>7-cluster solution</th></tr>
<tr><td rowspan="4">Cluster 1 (n=34)</td><td>Cluster 1 (n=6)</td><td>Cluster 1 (n=6)</td><td>Cluster 1 (n=6)</td><td>Cluster 1 (n=6)</td><td>Cluster 1 (n=6)</td></tr>
<tr><td rowspan="3">Cluster 2 (n=28)</td><td rowspan="3">Cluster 2 (n=28)</td><td>Cluster 2 (n=9)</td><td>Cluster 2 (n= 9)</td><td>Cluster 2 (n= 9)</td></tr>
<tr><td rowspan="2">Cluster 3 (n=19)</td><td rowspan="2">Cluster 3 (n=19)</td><td>Cluster 3 (n=12)</td></tr>
<tr><td>Cluster 4 (n=7)</td></tr>
<tr><td rowspan="3">Cluster 2 (n=25)</td><td rowspan="3">Cluster 3 (n=25)</td><td rowspan="2">Cluster 3 (n=16)</td><td rowspan="2">Cluster 4 (n=16)</td><td>Cluster 5 (n=5)</td><td>Cluster 5 (n=5)</td></tr>
<tr><td>Cluster 6 (n=11)</td><td>Cluster 6 (n=11)</td></tr>
<tr><td>Cluster 4 (n=9)</td><td>Cluster 5 (n=9)</td><td>Cluster 6 (n=9)</td><td>Cluster 7 (n=9)</td></tr>
</table>

Annex References:

Backhaus, K., Erichson, B., Plinke, W., & Weiber, R. (2016). *Multivariate Analysemethoden. Eine anwendungsorientierte Einführung*. Berlin/Heidelberg: Springer.

Everitt, B. S., Landau, S., Leese, M., & Stahl, D. (2011). *Cluster analysis* (5th Editio). Chichester, West Sussex, PO19 8SQ, United Kingdom: John Wiley & Sons, Ltd.

Milligan, G. W., & Cooper, M. C. (1985). An examination of procedures for determining the number of clusters in a data set. *Psychometrika*, *50*(2), 159–179. https://doi.org/10.1007/BF02294245

Wedel, M., & Kamakura, W. A. (2012). *Market segmentation. Conceptual and methodological foundations*. Springer US.

2 List of variables

Table A2: Description of variables

No.	*Variable name*	*Variable description*	*Scale level*	*Descriptive statistics*
CLUSTERING VARIABLES: Core characteristics of the transdisciplinary research mode				
Real-world orientation				
1	Research_ questions	**Overall research orientation** Coded from project proposals and project final reports if the project proposal was not available. Coding Command: 'Relation between real-world-oriented and scholarly research questions.' -2 'solely scholarly research questions' -1 'scholarly research questions dominate over real-world-oriented research questions' 0 'equal share of scholarly and real-world-oriented research questions' 1 'real-world-oriented research questions dominate over scholarly research questions' 2 'solely real-world-oriented research questions'	Interval [-2, -1, 0, 1, 2]	Min.: -1 Max: 2 Median: 1 Mean: 0.36 Std. Dev.: 0.92
2	Goal_applied	**Research goal generation of applicable knowledge or results** Coded from project proposals and project final reports if the project proposal was not available. Coding Command: 'In how far is the production of societally applicable knowledge or societally applicable results described as a goal of the research project? (e.g. measures, products, recommendations for action)' 0 'not mentioned' 1 'indirectly mentioned' 2 'named' 3 'described as central'"	Interval [0, 1, 2, 3]	Min.: 0 Max: 3 Median: 2 Mean: 1.92 Std. Dev.: 1.06
Intensity of interactions with actors from outside academia				
		Intensity of interaction with practitioners from outside academia Question from questionnaire: 'Were persons from outside academia involved in your project? e.g. persons from the economy, politics or (organized) civil society [Multiple answers possible]'?		
3	No_ practitioners	'No'	Binary [0,1]	Freq.: 6/59 (10.17%)
4	Practitioners_ consulting	'Yes, as specific target audience' or 'else' and in the subsequent qualitative text field practitioners were described as expert interview partners or field contacts (e.g. research site providers)	Binary [0,1]	Freq.: 10/59 (16.95%)
5	Practitioners_ shortterm	'Yes, as a short-term companion'	Binary [0,1]	Freq.: 29/59 (49.15%)
6	Practitioners_ longterm	'Yes, as an external, long-term companion'	Binary [0,1]	Freq.: 24/59 (40.68%)
7	Practitioners_ equal	'Yes, as an equal research partner'	Binary [0,1]	Freq.: 12/59 (20.34%)
8	Practitioners_ initiating	'Yes, as an initiator'	Binary [0,1]	Freq.: 5/59 (8.47%)
9	Practitioners_PI	Yes, as a principal investigator'	Binary [0,1]	Freq.: 4/59 (6.78%)

No.	*Variable name*	*Variable description*	*Scale level*	*Descriptive statistics*
10	Knowledge_ integration	**Explicit application of methods of knowledge integration in the interaction with practitioners from outside academia** 'Did you explicitly apply methods of knowledge integration?' 0 'no' 1 'yes'	Binary [0,1]	Freq.: 16/59 (27.12%)
11	Practitioners_ decisions	**Practitioners say in project decisions** Question from the questionnaire: 'Were the practitioners involved in the decision making within the project?' 0 'no' 1 'yes'	Binary [0,1]	Freq.: 24/59 (40.68%)
12	Practitioner_ heterogeneity	**Number of societal sectors involved** This variable is generated from the variables describing the societal sectors the practitioners on the project originate from (see Variables 24 to 27) For this variable the number of different sectors that practitioner originate from is summated.	Interval [0 - 4]	Min.: 0 Max: 4 Median: 2 Mean: 1.66 Std. Dev.: 1.06
Type of societal actors involved				
		Societal Sector which is represented by the practitioners in the project Open question in the questionnaire: 'If non-academic persons were involved, which persons or person groups were these specifically? [Text field]' The resulting open text material was coded according to the following categories:		
13	Practitioners_ government	The involved person/person group belongs to the societal sector 'government'	Binary [0,1]	Freq.: 34/59 (57.63%)
14	Practitioners_ private	The involved person/person group belongs to the societal sector 'private'	Binary [0,1]	Freq.: 33/59 (55.93%)
15	Practitioners_ civic	The involved person/person group belongs to the societal sector 'civic' (organized civil society, e.g. NGOs)	Binary [0,1]	Freq.: 18/59 (30.51%)
16	Practitioners_ citizens	The involved person/person group belongs to the societal sector 'citizens'	Binary [0,1]	Freq.: 8/59 (13.56%)
Type of practitioner contributions				
		Active contributions of practitioners Question from the questionnaire: 'To which of these areas did the practitioners in your project contribute? [Multiple answers possible, please select all answers that apply]'		
17	Problem_ definition	'Problem identification'	Binary [0,1]	Freq.: 30/59 (50.85%)
18	Research_ question	'Definition of the research question'	Binary [0,1]	Freq.: 11/59 (18.64%)
19	Knowledge	'Provision of knowledge on the field of action'	Binary [0,1]	
20	Needs_goals	'Formulation of needs and goals'	Binary [0,1]	Freq.: 36/59 (61.02%)
21	Norms_values	'Formulation of values and normative contributions'	Binary [0,1]	Freq.: 22/59 (37.29%)
22	Conditions_of_ change	'Formulation of conditions of change in the field of practice'	Binary [0,1]	Freq.: 25/59 (42.37%)
23	Product_ development	'Product development'	Binary [0,1]	Freq.: 12/59 (20.34%)
24	Resources	'Project resources (Contribution to financial or material project resources)'	Binary [0,1]	Freq.: 12/59 (20.34%)

No.	Variable name	Variable description	Scale level	Descriptive statistics
25	Assessment	'Assessment of project results, products or recommendations for action'	Binary [0,1]	Freq.: 41/59 (69.49%)
26	Dissemination	'Communication or sharing of project results, recommendations for action, etc.'	Binary [0,1]	Freq.: 39/59 (66.10%)
27	Implementation	'Implementation of insights, strategies or products in the field of practice'	Binary [0,1]	Freq.: 29/59 (49.15%)

THE ENVIRONMENT OF TRANSDISCIPLINARY RESEARCH

Funding context				
		Funding context 'German federal ministry of education and research' The German Federal Ministry of Education and Research (Bundesministerium für Bildung und Forschung, BMBF) launches and funds research according to current sustainability challenges. The following variables capture the affiliation of the projects to BMBF funding and the programmatic funding lines of the BMBF:		
28	BMBF	Project was funded by the German Federal Ministry of Education and Research	Binary [0,1]	Freq.: 44/59 (74.58%)
29	Social-ecological-research	Project within the BMBF funding program 'Socio-ecological research'	Binary [0,1]	Freq.: 15/59 (25.42%)
30	Economics_for_sustainability	Project within the BMBF funding program 'Economics for sustainability'	Binary [0,1]	Freq.: 8/59 (13.56%)
31	Climate_adaptation	Project within the BMBF funding program 'Climate protection and adaptation'	Binary [0,1]	Freq.: 3/59 (5.08%)
32	Biodiversity_conservation	Project within the BMBF funding program 'Conservation of biodiversity'	Binary [0,1]	Freq.: 1/59 (1.69%)
33	Sustainable_water_management	Project within the BMBF funding program 'Sustainable water management'	Binary [0,1]	Freq.: 1/59 (1.69%)
34	Resource_efficiency	Project within the BMBF funding program 'Resource efficiency technologies'	Binary [0,1]	Freq.: 1/59 (1.69%)
35	Sustainable_land_management	Project within the BMBF funding program 'Sustainable land management'	Binary [0,1]	Freq.: 15/59 (25.42%)
		Funding context of German research foundation The German Research Foundation (Deutsche Forschungsgemeinschaft, DFG) funds bottom-up projects as individual grants or in coordinated formats. The following variables capture the project´s affiliation to DFG funding and the specific formats:		
36	DFG	Project was funded by the German Research Foundation	Binary [0,1]	Freq.: 15/59 (25.42%)
Interinstitutional Collaborations				
37	Institutional_heterogeneity	**Number of academic institution types involved** This variable is generated from the variables describing the institutional affiliations of the scholars on the project (see Variables 37 to 41). For this variable the number of different institutions that scholars originate from is summated.	Interval [0 - 5]	Min.: 1 Max: 5 Median: 2 Mean: 2.03 Std. Dev.: 0.98

No.	Variable name	Variable description	Scale level	Descriptive statistics
		Share of institutional affiliations of scholars working on the research project A list of involved scholars was generated with information from research proposals and final reports as well as project webpages. For each scholar the institutional affiliation at the time of the research project was noted or researched online and coded according to the following categories. The number of scholars affiliated with each type of institution has been divided by the overall number of scholars working on the research project.		
38	Share_ university	Share of scholars located at a university	Interval [0 - 1]	Min.: 0 Max: 1 Median: 0.64 Mean: 0.64 Std. Dev.: 0.35
39	Share_non_ university	Share of scholars located at a big German non-university research institute (e.g. Helmholtz Centre, Leibniz Association, Fraunhofer Society, etc.) which are jointly funded by the state and the federal state	Interval [0 - 1]	Min.: 0 Max: 0.78 Median: 0 Mean: 0.07 Std. Dev.: 0.18
40	Share_state_ research	Share of scholars located at a state agency	Interval [0 - 1]	Min.: 0 Max: 0.25 Median: 0 Mean: 0.01 Std. Dev.: 0.04
41	Share_non_ profit_research	Share of scholars located at a private, but not for profit (non-profit) research institute (e.g. Institute for Applied Ecology, Institute for Social-Ecological Research, Institute for Ecological Economy Research, etc.)	Interval [0 - 1]	Min.: 0 Max: 0.86 Median: 0 Mean: 0.13 Std. Dev.: 0.22
42	Share_private_ research	Share of scholars located at a private research institute	Interval [0 - 1]	Min.: 0 Max: 1 Median: 0 Mean: 0.09 Std. Dev.: 0.22
Disciplinary setup				

No.	Variable name	Variable description	Scale level	Descriptive statistics
		Disciplinary setup Share of scholars of different disciplines working on the research project. A list of involved scholars was generated with information from research proposals and final reports as well as project webpages. For each scholar the individual disciplinary background based on their last qualification at the time of the research project was noted or researched online and coded according to the following categories. The categories are based on the taxonomy of scientific disciplines of Web of Science[1]. The number of scholars affiliated with each discipline has been divided by the overall number of scholars working on the research project.		
43	Institutional_ heterogeneity	**Number of disciplinary perspectives involved** This variable is generated from the variables describing the disciplinary assignation of the scholars on the project (see Variables 43 to 48). For this variable the number of disciplinary perspectives is summated.	Interval [0 - 6]	Min.: 1 Max: 6 Median: 2 Mean: 2.42 Std. Dev.: 1.13
44	Share_life_ sciences	Share of scholars assigned to life sciences and biomedicine according to their personal qualification	Interval [0 - 1]	Min.: 0 Max: 0.50 Median: 0 Mean: 0.05 Std. Dev.: 0.10
45	Share_physical_ sciences	Share of scholars assigned to physical sciences according to their personal qualification	Interval [0 - 1]	Min.: 0 Max: 0.29 Median: 0 Mean: 0.022 Std. Dev.: 0.06
46	Share_ technology	Share of scholars assigned to technology according to their personal qualification	Interval [0 - 1]	Min.: 0 Max: 0.60 Median: 0 Mean: 0.07 Std. Dev.: 0.14
47	Share_arts_ humanities	Share of scholars s with the disciplinary affiliation to Arts and Humanities according to their personal qualification	Interval [0 - 1]	Min.: 0 Max: 1 Median: 0 Mean: 0.04 Std. Dev.: 0.18
48	Share_social_ sciences	Share of scholars with the disciplinary affiliation to social sciences according to their personal qualification	Interval [0 - 1]	Min.: 0 Max: 1 Median: 0.50 Mean: 0.48 Std. Dev.: 0.32

[1] https://images.webofknowledge.com/images/help/WOS/hp_research_areas_easca.html (last visited: 25.04.2020)

No.	Variable name	Variable description	Scale level	Descriptive statistics
49	Share_ interdisciplinary_ scholars	Share of scholars with the disciplinary affiliation to more than one discipline according to their personal qualification	Interval [0 - 1]	Min.: 0 Max: 0.67 Median: 0.2 Mean: 0.22 Std. Dev.: .190
50	*Share_no_ information*	*Share of scholars on the project for which the disciplinary affiliation is unknown*		*Min.: 0* *Max: 1* *Median: 0* *Mean: 0.04* *Std. Dev.: 0.18*
Spatial scale				
		Spatial scale Coded from project proposals and project final reports if the project proposal was not available. Coding Command: 'Spatial area the research project referred to.'		
51	International	International scale	Binary [0,1]	Freq.: 9/59 (15.25%)
52	National	National scale	Binary [0,1]	Freq.: 16/59 (27.12%)
53	Regional	Regional scale	Binary [0,1]	Freq.: 19/59 (32.20%)
54	Municipal	Municipal scale	Binary [0,1]	Freq.: 11/59 (18.64%)
55	No_spatial_ reference	No spatial perspective	Binary [0,1]	Freq.: 4/59 (6.78%)
SOCIETAL AND ACADEMIC OUTPUTS AND IMPACTS				
Societal outputs and impacts				
56	Societal_ productivity	**Societal productivity** Index for outputs of the research project related to interacting or sharing insights with society in relation to the funding sum available to the project. The numbers of the respective activities were collected from project reports, project webpages and lists provided by the PI. The activities are weighed relatively to their expected workload for project employees, summated and divided by the funding sum as stated/provided by the funding agency. The funding sum is divided by 1.000.000 to receive the index of societal activities per million euro funding sum. societal_productivity = (n_publication_for_practice*1.5 + n_newspaper_article + n_press_release*0.25 + n_newsletter*0.25 + n_flyer*0.25 + n_presentation_for_practitioners*0.5 + n_event_for_practitioners*1.5) / (funding_sum / 1.000.000)	Interval [0 - ∞]	Min.: 0 Max: 103.85 Median: 7.41 Mean: 12.63 Std. Dev.: 18.50

No.	*Variable name*	*Variable description*	*Scale level*	*Descriptive statistics*
57	Societal_impact	**Depth of societal impact** Index for the depth of societal impacts of the research project as reported by the PI. The qualitative text material of two open questions from the questionnaire were coded according to the following categories: ‚If your project results were of importance for practitioners or society in general: What are the results and who are the target audience for these results?' [Text field] ‚Do you know if and how your research results are perceived or implemented by real-world actors and civil society?' [Text field] ‚Recognition' ‚Discussion' ‚Test' ‚Application' ‚Continuation/Implementation' Coded values were combined in a weighed summative index: idepth = recognition + (discussion*2) + (test*3) + (application*4) + (continuation*5)	Interval [0 - ∞]	Min.: 0 Max: 8 Median: 2 Mean: 2.29 Std. Dev.: 2.19
Academic outputs and impacts				
58	Academic_ productivity	**Academic productivity** Index for outputs of the research project related at interacting or sharing insights with society in relation to the funding sum available to the project. The numbers of the respective activities were collected from project reports, project webpages and lists provided by the PI. The activities are weighed relatively to their expected workload for project employees, summated and divided by the funding sum as stated/provided by the funding agency. The funding sum is divided by 1.000.000 to receive the index of academic activities per million euro funding sum. academic_productivity = (n_peer_reviewed_article*2 + n_book_chapter + n_anthology*2 + n_monograph*5 + n_non_peer_reviewed + n_working_discussion_paper + n_conference_proceeding + n_scientific_presentation*0.5 + n_scientific_event*1.5) / (funding_sum / 1.000.000)	Interval [0 - ∞]	Min.: 3.71 Max: 227.34 Median: 47.39 Mean: 58.94 Std. Dev.: 47.19
59	Academic_ impact	**Academic impact** As an indicator for academic impact the sum of citations within five years after publication of all project publications is divided by the project´s funding sum as provided by the funding agency. The funding sum is divided by 1.000.000 to receive the index citations per million euro funding sum.	Interval [0 - ∞]	Min.: 0 Max: 5910.89 Median: 41.39 Mean: 277.25 Std. Dev.: 809.41

PROJECT METRICS

No.	*Variable name*	*Variable description*	*Scale level*	*Descriptive statistics*
60	Funding_sum	**Funding sum** Funding sum as stated by the funding agency.	Interval [0 - ∞]	Min.: 79K€ Max: 4274K€ Median: 512K€ Mean: 718K€ Std. Dev.: 709K€
61	Funding_ duration	**Funding duration** Funding duration calculated from funding start date and funding end date as stated by the funding agency.	Interval [0 - ∞]	Min.: 27 Max: 144 Median: 41 Mean: 47.61 Std. Dev.: 23.73
62	Funding_ start_date	**Funding start date** Funding start date as stated by the funding agency.	Date	Min.: 01.01.1997 Max: 03.01.2008 Median: 15.12.2005

3 Results tables (detailed)

Table A3. The five research mode clusters described with the variables used to cluster the cases: the core characteristics of the transdisciplinary research mode (Hypothesis 1) (n = 59)

	Cluster 1 (n = 6)				**Cluster 2** (n = 9)				**Cluster 3** (n = 19)				**Cluster 4** (n = 16)				**Cluster 5** (n = 9)			
Variable	***M***	***SD***	***Mdn***	****Diff.***	***M***	***SD***	***Mdn***	****Diff.***	***M***	***SD***	***Mdn***	****Diff.***	***M***	***SD***	***Mdn***	****Diff.***	***M***	***SD***	***Mdn***	****Diff.***
(1) Real-world orientation																				
Research_question	-0.33	0.82	-0.50	4|5	0.33	1.12	1.00		0.00	0.94	0.00	4|5	0.63	0.62	1.00	1|3	1.11	0.60	1.00	1|3
Goal_applied	0.83	0.75	1.00	3|4|5	0.89	1.05	1.00	3|4|5	1.90	0.86	2.00	1|2|4|5	2.56	0.63	3.00	1|2|3	2.56	0.88	3.00	1|2|3
(2) Intensity of interactions																				
No_practitioners	1.00	0.00	1.00	2|3|4|5	0.00	0.00	0.00	1	0.00	0.00	0.00	1	0.00	0.00	0.00	1	0.00	0.00	0.00	1
Practitioners_consulting	0.00	0.00	0.00	2	1.00	0.00	1.00	1|3|4|5	0.05	0.23	0.00	2	0.00	0.00	0.00	2	0.00	0.00	0.00	2
Practitioners_shortterm	0.00	0.00	0.00	3|4	0.00	0.00	0.00	3|4	0.69	0.48	1.00	1|2	0.81	0.40	1.00	1|2	0.33	0.50	0.00	5
Practitioners_longterm	0.00	0.00	0.00	4	0.00	0.00	0.00	3|4	0.42	0.51	0.00	2|4	0.81	0.40	1.00	1|2|3|5	0.33	0.50	0.00	4
Practitioners_equal	0.00	0.00	0.00	5	0.00	0.00	0.00	5	0.05	0.23	0.00	5	0.19	0.40	0.00	5	0.89	0.33	1.00	1|2|3|4
Practitioners_inititating	0.00	0.00	0.00		0.00	0.00	0.00	5	0.00	0.00	0.00	5	0.13	0.34	0.00		0.33	0.50	0.00	2|3
Practitioners_PI	0.00	0.00	0.00		0.00	0.00	0.00		0.00	0.00	0.00	5	0.13	0.34	0.00		0.22	0.44	0.00	3
Knowledge_integration	0.00	0.00	0.00	4	0.00	0.00	0.00	4	0.32	0.48	0.00		0.50	0.52	0.50	1|2	0.22	0.44	0.00	
Practitioners_decision	0.00	0.00	0.00	4|5	0.11	0.33	0.00	4|5	0.16	0.37	0.00	4|5	0.75	0.45	1.00	1|2|3	0.89	0.33	1.00	1|2|3
Practitioner_heterogeneity	0.00	0.00	0.00	3|4|5	1.67	1.00	2.00	1	1.90	0.94	2.00	1	2.06	1.06	2.00	1|2	1.56	0.73	1.00	1
> Governmental actors	0.00	0.00	0.00	3|4|5	0.33	0.50	0.00	3	0.79	0.42	1.00	1|2	0.69	0.48	1.00	1	0.56	0.53	1.00	1
> Private actors	0.00	0.00	0.00	3|4|5	0.56	0.53	1.00		0.47	0.51	0.00	1|5	0.69	0.48	1.00	1	0.89	0.33	1.00	1|3
> Civic actors	0.00	0.00	0.00	3	0.22	0.44	0.00		0.47	0.52	0.00	1	0.38	0.50	0.00		0.11	0.33	0.00	
> Citizens	0.00	0.00	0.00		0.11	0.33	0.00		0.11	0.32	0.00		0.31	0.48	0.00		0.00	0.00	0.00	
(3) Type of practitioner contributions																				
Problem_definition	0.00	0.00	0.00	4|5	0.44	0.53	0.00		0.42	0.51	0.00	4	0.75	0.45	1.00	1|3	0.67	0.50	1.00	1
Research_question	0.00	0.00	0.00	5	0.11	0.33	0.00	5	0.00	0.00	0.00	4|5	0.19	0.40	0.00	3|5	0.78	0.44	1.00	1|2|3|4
Knowledge	0.00	0.00	0.00	2|3|4|5	0.67	0.50	1.00	1	0.63	0.50	1.00	1|4	0.94	0.25	1.00	1|3	0.89	0.33	1.00	1
Needs_goals	0.00	0.00	0.00	2|4|5	0.56	0.53	1.00	1|4	0.37	0.50	0.00	4|5	1.00	0.00	1.00	1|2|3	0.89	0.33	1.00	1|3
Norms_values	0.00	0.00	0.00	4	0.33	0.50	0.00	4	0.16	0.38	0.00	4	0.88	0.34	1.00	1|2|3|5	0.22	0.44	0.00	4
Product_development	0.00	0.00	0.00	5	0.00	0.00	0.00	5	0.00	0.00	0.00	4|5	0.31	0.48	0.00	3	0.78	0.44	1.00	1|2|3|4
Resources	0.00	0.00	0.00	5	0.00	0.00	0.00	5	0.11	0.32	0.00	5	0.31	0.48	0.00		0.56	0.53	1.00	1|2|3
Conditions_change	0.00	0.00	0.00	4|5	0.33	0.50	0.00		0.37	0.50	0.00		0.63	0.50	1.00	1	0.56	0.53	1.00	1
Assessment	0.00	0.00	0.00	3|4|5	0.44	0.53	0.00	4|5	0.74	0.45	1.00	1	0.88	0.34	1.00	1|2	1.00	0.00	1.00	1|2
Dissemination	0.00	0.00	0.00	3|4|5	0.33	0.50	0.00	4|5	0.63	0.50	1.00	1|4|5	0.94	0.25	1.00	1|2|3	1.00	0.00	1.00	1|2|3
Implementation	0.00	0.00	0.00	4|5	0.00	0.00	0.00	4|5	0.26	0.45	0.00	4|5	0.94	0.25	1.00	1|2|3	1.00	0.00	1.00	1|2|3

Notes. M = mean, SD = standard deviation, Mdn = median. *Diff. = significantly different from the cluster(s) named in the cell (statistical significance ≤ p .05), differences between clusters in binary variables were tested with chi-squared test, differences in interval scaled variables were tested using non-parametric Mann-Whitney U test. The variables on the sectoral origin of the practitioners (Governmental, private, civic actors and citizens) entered the clustering indirectly aggregated in the variable 'Practitioner_heterogeneity'.

Table A4. Relationship between cluster affiliation and funding scheme (Hypothesis 2) (n = 59)

	Cluster 1 (n = 6)				**Cluster 2** (n = 9)				**Cluster 3** (n = 19)				**Cluster 4** (n = 16)				**Cluster 5** (n = 9)			
Variable	***M***	***SD***	***Mdn***	****Diff.***	***M***	***SD***	***Mdn***	****Diff.***	***M***	***SD***	***Mdn***	****Diff.***	***M***	***SD***	***Mdn***	****Diff.***	***M***	***SD***	***Mdn***	****Diff.***
Funding context																				
BMBF (mission-oriented)	0.67	0.52	1.00		0.22	0.44	0.00	3|4|5	0.74	0.45	1.00	2	0.94	0.25	1.00	2	1.00	0.00	1.00	2
Social_ ecological_research	0.33	0.52	0.00		0.11	0.33	0.00		0.16	0.38	0.00		0.50	0.52	0,5	5	0.11	0.33	0.00	4
Economics_ for_sustainability	0.33	0.52	0.00	4|5	0.00	0.00	0.00		0.32	0.48	0.00	4|5	0.00	0.00	0.00	1|3	0.00	0.00	0.00	1|3
Climate_adaptation	0.00	0.00	0.00		0.00	0.00	0.00		0.05	0.23	0.00		0.06	0.25	0.00		0.11	0.33	0.00	
Biodiversity_ conservation	0.00	0.00	0.00		0.11	0.33	0.00	3|4|5	0.00	0.00	0.00	2	0.00	0.00	0.00	2	0.00	0.00	0.00	2
Sustainable_ water_management	0.00	0.00	0.00		0.00	0.00	0.00		0.00	0.00	0.00		0.06	0.25	0.00		0.00	0.00	0.00	
Resource_efficiency	0.00	0.00	0.00		0.00	0.00	0.00		0.00	0.00	0.00		0.00	0.00	0.00		0.11	0.33	0.00	
Sustainable_ land_management	0.00	0.00	0.00	5	0.00	0.00	0.00		0.21	0.42	0.00		0.31	0.48	0.00		0.67	0.50	0.00	1
DFG (bottom-up)	0.33	0,52	0.00		0.78	0.44	1.00	3|4|5	0.26	0.45	0.00	2	0.06	0.25	0.00	2	0.00	0.00	0.00	2

Notes. M = mean, SD = standard deviation, Mdn = median. *Diff. = significantly different from the cluster(s) named in the cell (statistical significance ≤ p .05), differences between clusters in binary variables were tested with chi-squared test, differences in interval scaled variables were tested using non-parametric Mann-Whitney U test.

Table A5. Differences between the five research mode clusters in inter-academic collaborations and spatial scale (Hypothesis 3 & 4) (n = 59)

	Cluster 1 (n = 6)				**Cluster 2** (n = 9)				**Cluster 3** (n = 19)				**Cluster 4** (n = 16)				**Cluster 5** (n = 9)			
Variable	***M***	***SD***	***Mdn***	****Diff.***	***M***	***SD***	***Mdn***	****Diff.***	***M***	***SD***	***Mdn***	****Diff.***	***M***	***SD***	***Mdn***	****Diff.***	***M***	***SD***	***Mdn***	****Diff.***
Interinstitutional collaborations																				
Institutional_heterogeneity	1.83	0.75	2	2	1.11	0.33	1.00	1|3|4	1.84	0.69	2.00	2	2.00	1.15	2.00	2	1.88	0.99	1.50	
Share_university	0.61	0.35	0.61	2|4	0.93	0.20	1.00	1|3	0.74	0.27	0.78	2	0.58	0.38	0.56	2	0.58	0.46	0.67	
Share_non-university	0.23	0.31	0.11	2	0.00	0.00	0.00	1	0.08	0.19	0.00		0.03	0.11	0.00		0.11	0.23	0.00	
Share_state_research	0.00	0.00	0.00		0.00	0.00	0.00		0.03	0.07	0.00		0.01	0.04	0.00		0.00	0.00	0.00	
Share_non-profit_research	0.16	0.25	0.00		0.07	0.20	0.00		0.07	0.12	0.00		0.19	0.28	0.00		0.20	0.28	0.10	
Share_private_research	0.00	0.00	0.00		0.00	0.00	0.00	4	0.09	0.24	0.00		0.18	0.32	0.00	2	0.12	0.23	0.00	
Interdisciplinary collaborations																				
Disciplinary_heterogeneity	2.00	1.10	2.00	4	1.44	0.73	1.00	3|4	2.53	1.02	2.00	2	2.88	0.72	3.00	1|2	2.67	1.73	2.00	
Share_life_sciences	0.08	0.20	0.00		0.07	0.15	0.00		0.03	0.05	0.00		0.05	0.09	0.00		0.03	0.09	0.00	
Share_physical_sciences	0.02	0.05	0.00		0.00	0.00	0.00		0.01	0.04	0.00		0.04	0.08	0.00		0.03	0.06	0.00	
Share_technology	0.02	0.05	0.00		0.00	0.00	0.00	3|4	0.08	0.14	0.00	2	0.10	0.18	0.00	2	0.09	0.18	0.00	
Share_arts_humanities	0.00	0.00	0.00		0.11	0.33	0.00		0.01	0.03	0.00		0.09	0.33	0.00		0.00	0.00	0.00	
Share_social_sciences	0.67	0.26	0.56		0.40	0.36	0.33		0.49	0.31	0.50		0.43	0.31	0.44		0.53	0.40	0.56	
Share_interdisciplinary	0.21	0.26	0.11		0.12	0.19	0.00	4	0.22	0.18	0.20		0.26	0.15	0.25	2	0.22	0.24	0.17	
Missings on the disciplinary shares	*0.00*	*0.00*	*0.00*	*2|3*	*0.31*	*0.27*	*0.33*	*1*	*0.16*	*0.20*	*0.00*	*1*	*0.02*	*0.31*	*0.08*		*0.10*	*0.39*	*0.12*	
Spatial perspective																				
Perspective_international	0.67	0.52	1.00	2|3|4|5	0.11	0.33	0.00	1	0.16	0.38	0.00	1	0.06	0.25	0.00	1	0.00	0.00	0.00	1
Perspective_national	0.00	0.00	0.00		0.33	0.50	0.00		0.26	0.45	0.00		0.31	0.48	0.00		0.33	0.50	0.00	
Perspective_regional	0.17	0.41	0.00		0.56	0.53	1.00	5	0.37	0.50	0.00		0.31	0.48	0.00		0.11	0.33	0.00	2
Perspective_municipal	0.17	0.41	0.00		0.00	0.00	0.00		0.21	0.42	0.00		0.19	0.40	0.00		0.33	0.50	0.00	
No_spatial_perspective	0.00	0.00	0.00		0.00	0.00	0.00		0.00	0.00	0.00	5	0.13	0.34	0.00		0.22	0.44	0.00	3

Notes. M = mean, SD = standard deviation, Mdn = median. *Diff. = significantly different from the cluster(s) named in the cell (statistical significance ≤ p .05), differences between clusters in binary variables were tested with chi-squared test, differences in interval scaled variables were tested using non-parametric Mann-Whitney U test.

Table A6. Differences between the five research mode clusters in their societal as well as academic productivity and impacts (Hypotheses 5 & 6) (n = 59)

	Cluster 1 (n = 6)				**Cluster 2** (n = 9)				**Cluster 3** (n = 19)				**Cluster 4** (n = 16)				**Cluster 5** (n = 9)			
Variable	***M***	***SD***	***Mdn***	****Diff.***	***M***	***SD***	***Mdn***	****Diff.***	***M***	***SD***	***Mdn***	****Diff.***	***M***	***SD***	***Mdn***	****Diff.***	***M***	***SD***	***Mdn***	****Diff.***
Societal outputs and impacts																				
Societal_productivity	16.36	15.98	14.34		2.51	3.80	1.04	4|5	9.64	17.81	6.51	4	19.77	25.36	9.90	3|2	13.87	11.76	8.14	2
Societal_impact	1.84	1.47	1.50	5	0.67	1.12	0.00	4|5	1.05	1.35	1.00	4|5	4.13	2.45	4.50	2|3	3.56	1.24	4.00	1|2|3
Academic outputs and impacts																				
Academic_productivity	91.40	37.65	83.81	4|5	69.03	45.32	58.43	5	74.71	58.50	47.39	5	42.09	28.17	44.52	1	23.89	23.93	16.14	1|2|3
Academic_impact	1330.71	2273.13	410.64	3|4|5	267.32	320.42	72.47	5	249.49	418.35	110.76	1|5	68.18	113.94	22.68	1|5	15.19	23.64	0.00	1|2|3|4

Notes. M = mean, SD = standard deviation, Mdn = median. *Diff. = significantly different from the cluster(s) named in the cell (statistical significance ≤ p .05), differences between clusters in binary variables were tested with chi-squared test, differences in interval scaled variables were tested using non-parametric Mann-Whitney U test.

Table A7. Comparison of project metrics for the five research mode clusters

	Cluster 1 (n = 6)				**Cluster 2** (n = 9)				**Cluster 3** (n = 19)				**Cluster 4** (n = 16)				**Cluster 5** (n = 9)			
Variable	***M***	***SD***	***Mdn***	****Diff.***	***M***	***SD***	***Mdn***	****Diff.***	***M***	***SD***	***Mdn***	****Diff.***	***M***	***SD***	***Mdn***	****Diff.***	***M***	***SD***	***Mdn***	****Diff.***
Funding_sum (K€)	857.42	976.35	431.33		873.21	1403.57	240.05	4	492.80	288.81	464.06	4	823.16	504.98	689.21	2|3	758.30	478.72	659.65	
Funding_duration	51.67	16.74	43.50		65.00	39.23	43.00		47.47	25.43	39.00		41.94	13.25	39.50		37.89	7.74	36.00	
Funding_start_date			15.12.2002				01.03.2002				01.07.2006				15.09.2005				01.10.2006	

Notes. M = mean, SD = standard deviation, Mdn = median. *Diff. = significantly different from the cluster(s) named in the cell (statistical significance ≤ p .05), differences between clusters in binary variables were tested with chi-squared test, differences in interval scaled variables were tested using non-parametric Mann-Whitney U test.

Environmental Science and Policy 101 (2019) 147–155

Contents lists available at ScienceDirect

Environmental Science and Policy

journal homepage: www.elsevier.com/locate/envsci

Linking modes of research to their scientific and societal outcomes. Evidence from 81 sustainability-oriented research projects

Jens Newig[a,*], Stephanie Jahn[a], Daniel J. Lang[a], Judith Kahle[a], Matthias Bergmann[a,b]

[a] Leuphana University Lüneburg, Faculty of Sustainability, Universitätsallee 1, 21335, Lüneburg, Germany
[b] Institute for Social-Ecological Research, Hamburger Allee 45, 60486, Frankfurt am Main, Germany

ARTICLE INFO

Keywords:
Transdisciplinarity
Research evaluation
Sustainability
Impact assessment
Mixed-Methods approach

ABSTRACT

Sustainability-oriented research has increasingly adopted "new" modes of research promoted under labels such as 'post-normal science', 'mode 2 knowledge production' or 'transdisciplinarity', aiming to address societally relevant problems and to produce 'socially robust' knowledge by involving relevant scientific disciplines and non-academic actors into the research.

We present the results of a comparative quantitative analysis of 81 completed sustainability-oriented research projects, coupled with an in-depth study of six projects, to empirically investigate the assumed connections between research modes and societal and academic project outcomes.

Statistical analysis suggests that contributions from practitioners in early phases of research projects positively influence certain societal and practice-relevant outcomes. By contrast, including non-academic actors and practitioner knowledge into research negatively impacts academic outputs and citations, indicating a trade-off between academic and societal impacts. Yet projects which apply structured methods of knowledge integration score generally higher on academic outputs and citations. Moreover, the funding context affects both research mode and research outcomes. Finally, practitioner involvement negatively affects completing of PhD projects.

Findings from the in-depth study reinforce a trade-off between the societal and academic impact of interdisciplinary and transdisciplinary sustainability-oriented research. We find that projects which had a double research objective on academic and societal outcomes but which did not specify how to realize both, neglected either the academic or the societal impact during the research process. Moreover, we find that a well-designed combination of disciplinary as well as inter- and transdisciplinary project phases helped projects to meet both demands.

1. Introduction

Sustainability-oriented research has increasingly adopted new modes of research, promoted under labels such as 'post-normal science' (Funtowicz and Ravetz, 1993), 'new modes of knowledge production' (*e.g.*Nowotny et al., 2004) and 'transdisciplinarity' (*e.g.*Bergmann et al., 2005; Hirsch Hadorn et al., 2008). The rationale of these modes of research is to effectively deal with societally relevant problems and to produce 'socially robust' knowledge. Key elements include collaboration across scientific disciplines, a focus on real-world problems and the involvement of actors from government, administration, business and/or civil society in the research process (Jahn et al., 2012; Lang et al., 2012).

Once seen as radical innovation, these "new" modes of knowledge production have meanwhile established themselves in the canon of "normal" (Kuhn) research (Bogner et al., 2010). Public research funding programs have invested heavily into transdisciplinary (TD) research, such as the programme "Social-Ecological Research", funded by the German Ministry of Education and Research (BMBF) since 1999, with a funding volume of more than 130 Million Euro until 2015 (BMBF 2015). Such public expenditures, and the experience gained with TD research through these funded projects, provide both the opportunity and the need for systematic comparative analysis of TD-related research. This regards the difference between TD and 'non-TD' research, and different forms and degrees of TD research, including their academic as well as societal outcomes.

Some studies are available that analyze individual as well as multiple TD projects or funding lines (*e.g.*Wiek et al., 2014; De Jong et al., 2016; Hansson and Polk, 2018), and few studies provide evidence of linkages between research mode and its outcomes (Walter and Scholz,

* Corresponding author.
E-mail address: newig@uni.leuphana.de (J. Newig).

https://doi.org/10.1016/j.envsci.2019.08.008
Received 15 April 2019; Received in revised form 26 July 2019; Accepted 19 August 2019

2007; De Jong et al. 2016; Hansson and Polk, 2018). Notably, De Jong et al. (2016) find positive effects of researcher-practitioner interaction on societal impacts, studying 52 TD projects from the Netherlands. To the best of our knowledge, no comparative study on the actually employed research modes and the academic as well as societal outcomes of a larger number of research projects is available to date, let alone a comparison of TD against non-TD projects (Zscheischler and Rogga, 2015). Research evaluation, while certainly an active field, has been mainly focusing on individuals as well as academic organizations and units. Some research funding programs have been evaluated. For example, Ruppert-Winkel et al. (2015), in studying the BMBF-initiated funding line "Social-Ecological research", point to trade-offs in achieving both societal and academic impact through TD research, which poses particular problems for young researchers.

In this study, we combined comparative analysis of 81completed sustainability-oriented research projects (large-N study) with six in-depth case studies (in-depth study) to empirically investigate the assumed connections between research modes and societal and academic project outcomes. The sample comprises projects with a substantial social science share funded by the two major German research funding institutions. These are the German Research Foundation (DFG) and the German Federal Ministry of Education and Research (BMBF). Studied projects cover a wide spectrum of research modes, ranging from basic research that is barely interdisciplinary to highly inter- and transdisciplinary projects including a variety of extra-academic actors in different project phases.

In the subsequent Section 2, we summarize the important concepts and theoretical claims on structure and functions of "new" modes of research, organized into four clusters of testable hypotheses. Section 3 reports on our research design including case selection, collected data, operationalization of variables, and the analytical methods applied. In Section 4, we present the results of testing the hypotheses, integrating quantitative findings (regression analysis) from the large-N study and qualitative process tracing results from the in-depth study. We close in Section 5 with an overall discussion and an outlook for further research.

2. Concepts and theory

A general assumption often mentioned in the literature is that research modes which actively engage non-academic actors[1] in the research process are more likely to produce societally relevant results and will thus generate more substantial societal impacts. One reasoning behind these assumptions is that research which takes into account 'demands' by potential users or other practitioners can specifically target its activities towards meeting such demands. Arguably, this is easier achieved in direct collaboration with those actors than by just consulting them (De Jong et al., 2016). Therefore, the more intensive the communication and collaboration, the more likely relevant results will be produced. Moreover, projects which involve practitioners early on rather than in later stages are expected to stand better chances of integrating practitioners' ideas and demands, in particular if non-academic actors already collaborate in formulating research questions (Enengel et al., 2012). Furthermore, it is argued that non-academic actors can also contribute non-scientific knowledge such as experiential or indigenous knowledge that is relevant for addressing the societal problem under investigation (Polk, 2014). Finally, non-academic actors participating in a research project may, through their professional networks, disseminate relevant research results more effectively than researchers by themselves (Phillipson et al., 2012). This leads to the formulation of

Hypothesis 1. An early and intensive involvement of relevant non-academic actors fosters the production of societally and practice-relevant knowledge and its application.

Successful knowledge co-production in research projects among academics of multiple disciplines and non-academic actors cannot be taken for granted. This even applies to working in purely scientific teams, as studies in the field of Science of Team Science have shown (for a comprehensive overview see Hall et al., 2018). It has therefore been suggested that specific structured methods of knowledge integration or comprehensive methodological frameworks such as participatory and collaborative modelling (Basco-Carrera et al., 2017), scenario planning and visioning (Sheppard et al., 2011), or the TRANSFORM as well as the Transition Management Framework (see Wiek and Lang, 2016) can help to effectively integrate different strands of knowledge (see Scholz and Tietje, 2002; Lang et al., 2012; Bergmann et al., 2012), which again is expected to foster the creation of socially relevant knowledge (Fazey et al., 2014).

Hypothesis 2. Using structured methods of knowledge integration between academic and non-academic actors fosters the production of societally and practice-relevant knowledge and its application.

Turning to the academic outcomes of a research project, assumptions are less clear. While arguably, an opening up of academic research to other societal spheres enhances research relevance for those spheres, it is a contested issue whether and how such opening-up impacts on academic knowledge production. On the optimistic side, there is the assumption that involving practitioners enriches research with perspectives and insights on real-world problems, which can fundamentally challenge academic thinking and potentially produce innovative research approaches and outcomes (Vera, 2018).

Hypothesis 3a. An early and intensive involvement of relevant non-academic actors yields more innovative academic research outcomes.

On the downside, trade-offs between a more transdisciplinary research approach and academic productivity have repeatedly been mentioned. One reasoning is that practitioner interaction requires substantial time and resources which are then not available for research activities (Ruppert-Winkel et al., 2015). Moreover, it has been argued that transdisciplinary research – given its epistemological difference from 'basic' or merely 'applied' research – is more difficult to publish (Bergmann et al., 2005; Weingart, 2008; Kueffer et al., 2007).

Hypothesis 3b. An early and intensive involvement of non-academic actors decreases academic productivity and publishability.

Turning to the context of research projects, notably the funding context is of interest. It has been suggested that projects that emerged in response to specific thematic calls in mission-oriented research (*e.g.* standard European Union Horizon 2020 projects) tend to formulate unattainable goals in their proposals in order to outrival competing proposals. Consequently, the formulated goals are less likely to be achieved than those in non-thematically bound (bottom-up) funding contexts.

Hypothesis 4. Projects funded in a mission-oriented context are likely to be less effective in achieving their stated goals than those in a bottom-up funding context.

Finally, research projects often engage doctoral researchers who aim to complete a PhD within the project duration, or shortly thereafter. Projects which heavily involve non-academic actors may tend to overburden doctoral researchers as these are often in charge not only of conducting academic research but also of managing transdisciplinary and collaborative processes (Ruppert-Winkel et al., 2015; Haider et al., 2018).

Hypothesis 5. In highly transdisciplinary projects, doctoral theses are less likely to be completed.

[1] As the choice of participating actors has been found to matter (De Jong et al., 2016), we refer to 'relevant' non-academic actors.

3. Research design and methods

In order to empirically investigate the assumed connections between ‘new’ research modes and societal as well as academic project outcomes, we combined a comparative analysis of 81 completed sustainability-oriented research projects (large-N study) with six in-depth case studies (in-depth study).

3.1. Unit of analysis and case selection

Our unit of analysis is the research project. Under ‘research project’ we understand a temporally, financially and staff-wise limited unit of activities in relation to one or more related research goals. Hence, the unit of analysis is relatively clear-cut, allowing for insightful comparative empirical research.

Our universe of cases consists of all 141 completed sustainability-related research projects funded either by the German Research Foundation (DFG) or by the German Federal Ministry of Education and Research (BMBF), conducted between 2000[2] and 2012, which had a substantial social science share and which combined at least two disciplines. The two institutions were chosen because they constitute the most important public research funding bodies in Germany and because they differ substantially in their funding structures, which arguably impact on the research modes chosen by the funded projects: The DFG pursues a ‘bottom-up’ approach in which research proposals are evaluated only on their academic excellence, typically neither bound by topic nor by funding deadlines. By contrast, the BMBF regularly issues thematic calls – similar to those in European Union funding structures – with specific deadlines. The BMBF framework program ‘FONA’ (Research for Sustainable Development’ comprises several funding lines, one of which is the pioneering funding line ‘Social-Ecological Research’. This and other funding lines within ‘FONA’ explicitly encourage and often require research projects to pursue a transdisciplinary research mode, which should be based on societally relevant research goals and which should involve practitioners into the research (BMBF 2016). DFG-funded research, on the other hand, is not subject to any requirements as to the employed research mode. While the DFG mostly funds relatively small-scale individual projects with a typical volume of around 200 K€, funding one or two doctoral researchers, typical BMBF projects range from 500 to 1000 K€, often involving multiple doctoral and post-doctoral researchers. By analyzing both BMBF and DFG-funded projects, we assure a substantial variety of research modes – from basic research to applied as well as more or less transdisciplinary research projects –, which allows to study the effect of transdisciplinary *as opposed to less transdisciplinary* research modes.

To determine whether projects were sustainability-related we included projects which mentioned ‘sustainable’ or ‘sustainability’ in the project title or descriptions, excluding projects that used these terms only in the sense of ‘long-term’. From this universe, 81 complete datasets were produced in the large-N study, consisting of project documents and questionnaires completed by the respective head of project.

From this dataset, six cases were selected for the in-depth study, aiming to cover a diversity of projects with respect to project type, academic or non-academic project initiation, disciplinary focus, degree of transdisciplinarity, and funding context.

3.2. Data collection and material

In the ***large-N study,*** core concepts of the hypotheses were operationalized into a comprehensive set of variables. Sources for a systematic document analysis were the respective project proposal as well as the project report and lists of further project outcomes (*e.g.* publications, events, prizes) that emerged after the publication of the final project report. Additional information was gathered through a questionnaire filled in by project heads, who were also given the opportunity to check and validate project output lists assembled by us. All 141 identified projects were approached with a request to take part in our study, of which 81 projects supplied the relevant information (Table 1).

Of the six ***in-depth cases,*** three were funded by the DFG, another three by the BMBF (Table 2). One project was headed by practitioners, all others had academic project heads. As empirical material, project proposals, interim and final reports, as well as academic, non-academic publications and media responses were used for a structured content analysis. In total, 35 semi-structured interviews were conducted with project heads, research staff and practitioners involved as project partners, informants or data providers.

3.3. Methods of analysis

For the large-N study, quantitative data was either taken directly from standardized questionnaires or produced by coding project documents and qualitative questionnaire data. Multiple regression analysis was performed to test the relations between research mode and outcome variables. In the in-depth study, recorded interview transcripts and significant project-related documents underwent a structured content analysis. Causal process tracing (Blatter and Haverland, 2012; Mahoney, 2012), involving counterfactual analysis, was employed to test the above hypotheses, providing case-based insights into how the research mode connects to academic and societal outcomes (Table 2.

4. Findings

Below, we describe and discuss our empirical findings of the large-N and the in-depth study for each of the above formulated hypotheses.

4.1. Hypothesis 1: Non-academic actor involvement and societal project outcomes

In ***the large-N study,*** we operationalized the research mode “early and intensive involvement” through four independent variables: *Early_involvement* measures whether non-academic actors contributed to the identification of the research problem and to the formulation of a project’s research question. *Practitioner_values* measures whether non-academic actors contributed by formulating needs and goals, normative values or conditions for change in their field of practice. *Practitioner_knowledge* measures whether non-academic actors contributed with knowledge about the area of activity. *Practitioner_decision,* finally, measures whether non-academic actors were involved in relevant project decisions.

In our sample, projects’ societal impacts – the “production of societally and practice-relevant knowledge and its application” – included the production of practitioner guides, press coverage of projects, changes in policy by governmental actors, use of jointly developed products by private companies, or awareness raising on the part of certain publics, to name but a few. For quantitative analysis, societal impact was operationalized through four dependent variables, which relied on self-reporting by project heads (for a similar approach see De Jong et al., 2016): *Impact_depth* is a weighted index measuring whether research results were merely recognized by practitioners (weight 1), and/or discussed (weight 2), tested (weight 3), applied (weight 4) or continually implemented by practitioners (weight 5). *Impact_scale* is a weighted index measuring whether a project had impact on the project actors (weight 1), and/or on the wider local (weight 2), regional (weight 3), national (weight 4) or international (weight 5) scale. *Impact_sectors* sums up the number of sectors (media, education, civil

[2] Three of our analyzed DFG-funded projects were part of one of two Collaborative Research Centers, which already started in 1997 and 1999, respectively. The total durations of these Collaborative Research Centers largely cover our main investigation period 2000 and 2012.

Table 1
Structured overview of the 81 research projects studied.

	Federal Ministry of Education and Research (BMBF)	German Research Foundation (DFG)	Total
Number of projects	58	23	81
Funding volume (mean/std. dev.)	888 K€/713 K€	280 K€/292 K€	716 K€ / 679 K€
Project duration (mean/std. dev.)	44 months / 16 months	60 months / 38 months	48 months / 25 months
Project start date (median)	01 May 2006	01 June 2003	01 January 2006
Projects involving practitioners	50 (86%)	9 (39%)	59 (73%)

Table 2
Structured overview of the six in-depth cases.

	Disciplinary Hinge Project	Applied Project	Interdisciplinary Project	Transdisciplinary Project	Intervening Project	Practitioner Project
Funding context	DFG	DFG	BMBF	BMBF	DFG	BMBF
Funding volume category[a]	501–750 K€	< 250 K€	2001–7500 K€	501–750 K€	251–500 K€	< 250 K€
Project type	Subproject in joint project	Single project	Single project	Single Project	Subproject in joint project	Single project
Approx. duration	12 years	2 years	6 years	3 years	3 years	2.5 years
Initiation & lead	Academic	Academic	Academic	Academic	Academic	Non-academic
Research mode	Interdiscipl.	Interdiscipl	Transdiscipl.	Transdiscipl.	Transdiscipl.	Applied
Aiming for academic qualification	xx	–	xxx	–	x	–

[a] To ensure anonymity of the projects we provide here ranges of funding sums instead of the exact numbers.

society, business, government) in which a project had impact. *Impact_media* measures how often a project was mentioned by newspapers or magazines, radio or television (weighted by circulation), or by practitioner outlets. *Impact_total,* finally, is the arithmetic mean of all four impact variables.

In order to determine the link between the nature of non-academic actor involvement and the societal impact, we ran linear regression models (ordinary least squares – OLS) as depicted in Table 3. To capture non-academic actor involvement, we used the four above-mentioned variables *Early_involvement, Practitioner_decision, Practitioner_values,* and *Practitioner_knowledge*. As control factors we included the degree to which a project aimed at producing applied as opposed to strictly academic knowledge (*Goal_applied)*, the extent of project dissemination activities (*Dissemination*) and the total third-party funded project budget (*Funding_sum*).

Table 3 shows the results of our regression analysis. It comprises a total of twelve different regression models, with models (1a) to (1 h) aiming to explain *Impact_depth* as dependent variable, and models (2) to (5) referring to the remaining impact dimensions as dependent variables. As mentioned above, four variables capturing the nature of non-academic actor involvement and three controls were included as independent variables to explain the impact variables.

For *Impact_depth,* we first tested the explanatory role of the involvement variables individually, which yielded relatively high and significant effects (models 1a to 1d). However, adding more inedependent variables beyond the first two (1e) did not improve overall model fit (adjusted R^2; see models 1f and 1 g), which is likely due to the correlation among these factors. Therefore, we restricted further analyses (models 1 h to 5) to those two independent variables showing the strongest effects (*Early involvement* and *Practitioner_decision*). Including the control variables (1 h), only *Early_involvement* has a significant effect.

While all four impact variables are significantly correlated among each other (coefficients between 0.50 and .61), next to *Impact_depth,* only *Impact_media* was found to be significantly explained by research-mode variables (models 2, 3, 4, 5 in Table 3). Of all control variables, only *Dissemination* shows significant positive effects.

While overall model fit is not overly high in absolute terms (r^2 of 0.30, adjusted r^2 of 0.25 for the 'best' model 1 h), model 1 g still implies that 17% of the variance of *Impact_depth* can be explained by research mode only. Research mode thus does have non-negligible effect on impact.

Taken together, from our regression analysis of 81 cases, we cannot confirm that non-academic actor involvement generally improves

Table 3
Effects of practitioner involvement variables on societal impact variables (OLS regression).

	Dependent variable: Impact_depth								Impact_ sectors	Impact_ scale	Impact_ media	Impact total
Model no.	(1a)	(1b)	(1c)	(1d)	(1e)	(1f)	(1g)	(1h)	(2)	(3)	(4)	(5)
Early_involvement	.38***				.26*	.21	.21	.28*	.20	.05	.36**	.28*
Practitioner_decision		.38***			.26*	.20	.21	.16	− .05	.04	− .11	.03
Practitioner_values			.36**			.15	.16					
Practitioner_knowledge				.24*			− .03					
Goal_applied								.18	.07	.22	− .09	.11
Dissemination								.25*	.27*	.15	.33**	.34**
Funding_sum								− .09	− .14	− .21	− .09	− .18
Intercept	1.43***	1.38***	1.19**	1.44**	1.14**	0.95*	0.98*	0.44	.66**	1.56*	3.69	− .36*
Observations	81	81	81	81	81	81	81	81	81	81	81	81
R^2	.15	.14	.13	.06	.20	.21	.21	.30	.11	.12	.15	.23
Adjusted R^2	.13	.13	.12	.05	.18	.18	.17	.25	.05	.07	.10	.18
F-value	13.4***	13.2***	11.8**	4.9*	9.5***	6.8***	5.0**	6.3***	1.85	2.12	2.72*	4.60**
AIC	364.1	364.3	365.6	371.9	361.2	361.78	363.7	356.5				

Note: Depicted are standardized regression coefficients (beta values). Statistical significance is depicted as * p < .05; **p < .01; *** p < .001.

societal outcomes. Rather, practitioner involvement in early project phases – identification of research problems and formulation research questions – has shown to have a significant effect, but only on the depth of impact and on media impact, as well as on the total impact measure. Of the control variables, only the extent of dissemination strategies shows a positive influence on societal impacts, whereas the degree to which a project aimed at producing applied knowledge had no discernible effect, and the funding sum even showed a slightly negative effect on societal impacts.

In the ***in-depth study,*** two contrasting cases provided insights into causal relations between the involvement of non-academic actors in research processes and the societal project impacts.

The *Transdisciplinary Project* purposefully involved practitioners from politics, administration and industry. This served two major goals: First, to facilitate socially robust solutions to cope with anthropogenic hazards and, second, to empower practitioners to put the solutions to use. Over the course of the project, the co-produced societal output resulted in a practical guide. This guide, disseminated by researchers and practitioners, was used by several practitioners from different societal sectors: One practitioner from industry, formerly involved in the project, helped to initiate a non-academic project on a similar topic by adopting the integrated approach, one of the key results of the *Transdisciplinary Project*. Also an environmental state agency, not formerly involved in the project, published a flyer on anthropogenic hazards and how to cope with them based on the integrated solutions developed in the project.

However, as the project's topic, goals and methods, as well as team constellation were all decided by the researchers, we can hardly speak of an early practitioner involvement. Instead, we can speak of an intense and well targeted involvement as the practitioners' values and knowledge were pointedly incorporated along the research process. Several of the involved practitioners reported their grown motivation to actually apply the project's results after completion. Interviewees mentioned different intermediate effects during the development of the practical guide that ultimately increased the practitioners' agency, *e.g.* grown sensitivity for the societal relevance of the project's topic, recognition and trust in the academic competence of the researchers, experiential knowledge how to design and implement a topic-related project, and lack of result implementation planned by the researchers.

The Applied Project, which aimed for developing coping strategies to deal with natural hazards, involved practitioners as informants and interviewees only. Based upon their provided information, the interdisciplinary research team developed a practical guide. However, several practitioners reported that they barely recognized or used this guide. They explained this with having no need for the case-specific examples in the guide as they had already developed their own solutions. Presumably, if the practitioners had been involved more intensely in the development of the guide they might have become more aware of the general recommendations for action which were also part of the guide. At the same time, the researchers would have had the opportunity to adapt their societal project goals more to the actual needs of the non-academic actors. Nevertheless, important societal effects were reached via pointed dissemination by one of the project heads, among others to inform a law development process on federal state level.

Summarizing, the analysis of the *Transdisciplinary Project* suggests a causal relation between the intense involvement of non-academic actors and impact depth, as well as impact scale. Similar insights were found for the *Intervening Project* and the *Practitioner Project*. The *Applied Project*, on the other hand, demonstrates that societal impact is hardly achieved if practitioners are only involved as research objects in the development of practically-relevant project outputs. This is also reflected in the *Disciplinary Hinge Project*. However, the *Applied Project* also indicates that if disseminated well, a project's results can lead to societal impact even if it is not transdisciplinary.

4.2. Hypothesis 2: Knowledge integration methods and societal project outcomes

In the ***large-N study,*** the variable *Knowledge_integration* measured whether or not a project drew on structured methods to integrate non-academic and academic knowledge. Such methods included, for example, scenario building, SWOT analysis, development and application of models, multicriteria assessment, Delphi method, stakeholder workshops or moderated meetings, to name but a few. Analyzing only those 59 cases with at least some degree of practitioner involvement, we could not find significant relationships between this variable and societal project outcomes.

In the ***in-depth study,*** four projects deployed moderated workshops to include the practitioners in the research process: *Interdisciplinary, Transdisciplinary, Intervening* and *Practitioner Project*. Within the workshops, each project relied on different methods of knowledge integration, such as small group discussions, using boundary objects or group assessment tools. These methods provided the stage and the tools for transdisciplinary collaboration which in turn essentially bolstered the practically relevant outputs – but not necessarily the societal impact – of all four projects.

Only in two projects, *Intervening* and *Practitioner Project*, methods of knowledge integration were used to practically test societal results. In the projects both knowledge integration methods and the timing of their application within the overall research process were purposefully chosen to effectively incorporate different practical knowledges of the involved groups of practitioners. In the *Practitioner Project,* for instance, local governance actors were regularly involved via moderated workshops in order to finetune the project results and give way for the next research steps. By contrast, civil society was involved once via an information event and subsequent consulting to test a communication strategy for sustainable urban living. The trust that the practitioners, in turn, developed in the applicability of the results ultimately motivated them to further apply the results after project completion.

Summarizing, the in-depth study found weak evidence in support of a causal link between the selection, timing and way of applying methods of knowledge integration on the one hand and reaching impact depth on the other.

4.3. Hypotheses 3a and 3b: Non-academic actor involvement and academic research outcomes

To test the effect of non-academic actor involvement on academic research outcomes, we measured two dependent variables: *Publications* refers to a project's total volume of publications in academic journals and books as researched by our project team and validated by project leads. As our control variable *Funding_sum* is correlated extremely high (.73***) with the absolute number of project publications, we chose to define *Publications* as the number of publications per funding volume in million Euros. The variable *Citations* refers to the total citations of project publications in Google Scholar in the five years following publication (including the year of publication). Due to its distribution, we measured the decadic logarithm of a project's citations, and as with the previous variable, this value was then divided by the project's funding volume in million Euros. In the large-N study we did not investigate the effects on the innovative character of the project outputs and outcomes (Hypothesis 3a).

In our regression models (Table 4), we included the same involvement variables as in the above models for hypothesis 1, adding *Knowledge_integration*. The results of models 1–5 show that most variables individually are associated with *Publications*, showing significant negative effects for *Early_involvement, Practitioner_values, Practitioner_knowledge* and *Practitioner_decision*. In the more comprehensive model 6b, which includes the two controls *Goal_applied* and the variable *Practitioner_involvement* (measuring whether or not practitioners were involved in the project at all), we still find significant negative effects of

Table 4
Effect of practitioner involvement variables on academic publication output (OLS regression).

Dependent Variable: Publications per Million Euro funding sum							
Model no.	(1)	(2)	(3)	(4)	(5)	(6a)	(6b)
Early_involvement	−.25*						
Practitioner_decision		−.39***				−.30**	−.31**
Practitioner_values			−.29**				
Practitioner_knowledge				−.38***		−.25*	−.33*
Knowledge_Integration					.16	.33**	.30**
Goal_applied						−.22*	−.24*
Practitioners_involved							.14
Intercept	23.84***	26.23***	26.07**	28.74***	18.55***	33.06***	31.97***
Observations	81	81	81	81	81	81	81
R^2	.06	.15	.08	.14	.03	.34	.35
Adjusted R^2	.05	.14	.07	.13	.01	.31	.31
F-value	5.11*	13.84***	7.10**	13.29***	2.15	9.91***	8.09***
AIC	695.46	687.46	693.57	687.94	698.37	672.54	673.59

Note: Depicted are standardized regression coefficients (beta values). Statistical significance is depicted as * $p < .05$; ** $p < .01$; *** $p < .001$.

Practitioner_knowledge and *Practitioner_decision,* as well as a significant positive effect of *Knowledge_integration.* With an R^2 of 0.35 (adjusted R^2 of 0.31), the model shows a reasonable overall fit.

Turning to *Citations* (Table 5), we find essentially the same pattern but with lower effect sizes and statistical significance for all independent variables.

To conclude, we find relatively clear support for hypothesis 3b – namely that an early and intensive involvement of non-academic actors decreases academic productivity and recognition. Contrary to expectation, also knowledge contributions by practitioners show negative effects on academic outcomes. By contrast, the use of structured methods to integrate non-academic and academic knowledge is a highly significant positive predictor for academic outcomes.

In order to investigate hypotheses 3a and 3b in the ***in-depth study,*** we took academic publications but also the development of new theories, methods and data bases into account, as well as attendances in academic conferences. For academic outcome, we considered citations but also follow-up projects, as well as networking and exchange with other researchers outside the project.

From the four projects which involved practitioners as research partners, only the *Interdisciplinary* and the *Transdisciplinary Project* aimed for strong academic output in the sense of publications, while also pursuing applied goals. Both projects started publishing in an early phase and continued to do so throughout the research process. This became possible due to effectively distributed tasks among the involved researchers and a targeted combination of disciplinary, interdisciplinary and transdisciplinary research phases along the research process. In both projects, small disciplinary or interdisciplinary groups took over specific research tasks according to their prior research expertise and individual research interests. This allowed the researchers to make essential research contributions to the specific project. In the *Interdisciplinary Project*, researchers were jointly preparing and implementing a limited number of transdisciplinary workshops with practitioners, thus subdividing the respective workload among each other. In the *Transdisciplinary Project* small groups of researchers took turns preparing the workshops with practitioners while – in the meantime – the others could continue to work on the disciplinary and interdisciplinary research results. With these strategies, both projects reached strong academic outputs in the form of theoretical concepts, methodical innovations (in support of hypothesis 3a), data sets, as well as considerable numbers of academic publications (*Interdisciplinary Project*: 119; *Transdisciplinary Project*: 28), thus prociding counter-evidence for hypothesis 3b.

Despite the strong academic output, one researcher from the *Transdisciplinary Project* mentioned the enormous amount of time needed to prepare and implement the transdisciplinary workshops, including the choice of the methods of knowledge integration to be used. At the same time, the researcher stressed the limited output that the workshops provided for the next research steps in the project. In fact, those researchers who were less involved in the collaboration with the practitioners published – apart from the project lead – the most. Additionally, the same researcher reported initial difficulties to find a journal to publish the transdisciplinary research results.

Yet, transdisciplinary collaboration also essentially contributed to certain academic results in both projects. For instance, in the *Transdisciplinary Project* a method for actor network analysis could be

Table 5
Effect of practitioner involvement variables on citations of academic publications (OLS regression).

Dependent Variable: Decadic logarithm of a project's citations per Million Euro funding sum							
Model no.	(1)	(2)	(3)	(4)	(5)	(6a)	(6b)
Early_involvement	−.28*						
Practitioner_decision		−.35**				−.16	−.15
Practitioner_values			−.45***				
Practitioner_knowledge				−.47***		−.30**	−.22
Knowledge_Integration					−.13	.02	.05
Goal_applied						−.26*	−.24*
Practitioners_involved							−.12
Intercept	4.36***	4.72***	5.62***	5.99***	3.72***	7.57***	7.80***
Observations	81	81	81	81	81	81	81
R^2	.08	.12	.20	.22	.02	.31	.31
Adjusted R^2	.07	.11	.19	.21	.00	.27	.27
F-value	6.78*	11.27**	19.86***	22.20***	1.37	8.52***	6.89***
AIC	473.41	469.27	461.92	460.02	478.69	456.08	457.47

Note: Depicted are standardized regression coefficients (beta values). Statistical significance is depicted as * $p < .05$; ** $p < .01$; *** $p < .001$.

Table 6
Achievements of projects in different funding contexts.

Funding program		Reported overall goal attainment			Depth of reported societal impact			No. of publications p. Mio. € funding sum			No. of citations p. Mio. € funding sum		
	N	ø	sd.	med.	ø	sd.	med.	ø	sd.	med.	ø	sd.	med.
DFG	**23**	**5.4**	**1.1**	**6.0**	**1.3**	**2.8**	**0.0**	**30.3**	**21.2**	**28.9**	**282.8**	**316.3**	**176.0**
Individual grant	13	5.3	1.3	6.0	1.0	1.5	0.0	32.7	20.2	34.5	321.4	357.2	253.6
Project in Coll. Research Centre	10	5.6	0.8	6.0	1.6	4.1	0.0	28.4	22.5	26.2	232.5	263.6	148.1
BMBF	**58**	**5.8**	**0.9**	**6.0**	**2.5**	**1.3**	**2.0**	**16.5**	**15.0**	**13.6**	**238.2**	**805.7**	**36.7**
Climate protection/adaptation	4	5.5	1.0	6.0	2.3	2.1	2.5	9.9	7.6	9.7	29.0	54.6	2.6
Conservation of biodiversity	1	7.0	.	7.0	0.0	.	0.0	22.5	.	22.5	774.3	.	774.3
Economics for sustainability	11	5.5	1.2	6.0	1.4	1.6	1.0	26.9	21.0	21.2	868.6	1742.5	336.9
Resource efficiency technol.	1	6.0	.	6.0	3.0	.	3.0	10.0	.	10.0	64.0	.	64.0
Social-ecological Research	21	6.0	0.7	6.0	2.2	2.3	1.0	20.8	13.6	19.8	151.9	163.2	72.4
Sustainable land management	18	5.9	1.0	6.0	3.5	2.0	4.0	7.2	7.4	3.6	4.8	7.8	0.0
Sust. water management	1	6.0	.	6.0	6.0	.	6.0	12.9	.	12.9	25.8	.	25.8

Note: ø = arithmetic mean; sd = standard deviation; med. = median.

further developed, also because parts of it were tested by the involved researchers.

Ultimately, in the first five years after their completion, both projects had reached high citation rates. In the *Interdisciplinary Project*, no evidence was found for a causal link between the transdisciplinary research mode of the project and its academic impacts (hypothesis 3b). Yet there is evidence to suggest that the involvement of practitioners in the *Transdisciplinary Project* indeed produced several academic effects. For instance, a follow-up project partially involved the same actors and continued the transdisciplinary research on the topic. Also one of the practitioners joined a collaboration to integrate the project's findings into academic teaching. Another practitioner with close ties to academia provided funding to conduct a second round of the survey developed in the project.

To sum up, the in-depth study demonstrates that strong academic outputs and outcomes occur partly despite and partly precisely because of involving practitioners. Additional factors proved to be conducive to allow strong academic outcomes in transdisciplinary research projects, *i.e.* a constant focus on producing academic results, an effective division of tasks among the involved researchers, a purposeful combination of disciplinary, inter- and transdisciplinary research phases, as well as researchers with a strong individual research agenda.

4.4. Hypothesis 4: Funding context and goal achievement

The ***large-N study*** covers 58 projects funded in a mission-oriented context by the BMBF, and 23 projects funded in a "bottom-up" context by the DFG. In order to compare achievements across different funding contexts, the variable *Goal_achievement* measures self-reported overall project goal achievement. Moreover, we consider outcome variables as introduced above. Within the broad funding contexts of DFG and BMBF, respectively, we distinguish different DFG funding formats (individual grants versus sub-projects in large collaborative research centers) and different BMBF funding lines as displayed in Table 6.

We find, first of all, no significant[3] differences in goal achievement values between BMBF cases and DFG cases and no significant differences among the individual funding lines[4], and hence no support for hypothesis 4.

However, Table 6 shows substantial differences when it comes to societal and academic outcomes: Projects from a mission-oriented funding context (BMBF) score considerably higher on the depth of reported societal impact than bottom-up funded projects (DFG), with some notable differences within the two. Conversely, bottom-up funded projects (DFG) on average score considerably higher on publications and citations per unit of funding volume than mission-oriented projects (BMBF). Here again, we find differences across the sub-categories, with DFG individual grants showing higher publications and citations than sub-projects in collaborative research centers, and, most notably, among the different BMBF funding lines.

From these findings, we may conclude that while self-reported achievements relative to stated goals are consistently high and show no significant variation, we find a strong trade-off between societal and academic outcomes across the different funding formats and lines. Overall, the funding context appears to play a decisive role for achieving societal and academic outcomes, respectively.

For the ***in-depth study,*** the academic and societal goals stated in the project-related documents and by the various interview partners were compared to the funding criteria of the DFG and the BMBF funding lines. In addition, the goals were compared to the academic and societal outcomes reported to us.

As the BMBF made it compulsory for the *Interdisciplinary*, the *Transdisciplinary* and the *Practitioner Project* to pursue both academic and societal outcomes, these funding criteria in part determined the research design in the initiation phase of these projects, including the research topic, the research mode and the team composition. For instance, the *Practitioner Project,* which was originally conceptualized as a purely practical project, included academic expertise following BMBF's recommendation.

By contrast, the DFG's funding criteria generally focus on strong scientific rigor. However, in the case of the two subprojects in a collaborative research center, the DFG also shaped the projects' goals and stipulated their research modes. Concretely, in the first two funding periods, the DFG required strong interdisciplinary collaboration among the sub-projects of the overall collaborative research center, including the *Disciplinary Hinge Project.* For the third funding period, which is when the *Intervening Project* joined the collaborative research center, the DFG asked for a strong application and evaluation focus. In both cases, the projects adapted their research modes and team compositions accordingly.

In summary, it can be said that the different funding contexts directly affected the goal setting and project conceptualization of at least five projects in the in-depth study. More indirectly, it also affected the subsequent research process, results and impacts. However, other factors, independent from the funding context, played a more direct role with regard to reaching the project goals (see Hypotheses 1 to 3b).

[3] The performed t-test shows with a significance level of p = 0.06 no differences in the mean of *Goal_achievement* between projects in the mission-oriented funding context (BMBF) and bottom-up funded projects (DFG).

[4] The performed Bonferroni-test finds no significant differences in the *Goal_achievement* values between the nine sub groups of the individual funding lines, as the test hypothesis of the Bonferroni-test - that there are differences between the subgroups - can be rejected at a significance level of p = 0.61.

Table 7
Effect of practitioner involvement on completed PhD projects (OLS regression).

Dependent variable: Quota of completed PhD projects				
Model no.	(1)	(2)	(3)	(4)
Early involvement	−.15			
Practitioner decision		−.34*		
Practitioner values			−.07	
Practitioner knowledge				−.05
Funding sum	.06*	.12	.09	.07
Intercept	.74***	.76***	.71***	.72***
Observations	42	42	42	42
R^2	.03	.12	.01	.01
Adjusted R^2	−.02	.07	−.04	−.04
F-value	0.57	2.59$^+$	0.17	0.13
AIC	38.27	34.23	39.11	39.19

Note: Depicted are standardized regression coefficients (beta values). Statistical significance is depicted as $^+$ $p < .10$; * $p < .05$; ** $p < .01$; *** $p < .001$.

4.5. Hypothesis 5: Non-academic actor involvement and completed PhD projects

From our sample of 81 projects, 42 provided reliable information on PhD dissertations[5] . These 42 projects were used to quantitatively test the effect of involvement variables on the share of completed PhD theses per project. This we measure by dividing the number of PhD theses completed two years or later after project end (depending on the time of survey) by the number of theses planned at project start. While 24 projects succeeded in producing the planned number of completed PhDs, 18 projects did not. Across all 42 projects, in total 80 out of 106 planned PhD dissertations were finished successfully at the time of the survey.

Regression results (Table 7) show that all practitioner involvement variables display a negative relationship with the share of completed PhD projects, while only the relationship with *practitioner_decision* is statistically significant. Nevertheless, we can see a trend supporting hypothesis 5.

In the ***in-depth study,*** three of six projects aimed for and successfully completed doctoral dissertations or habilitations: The *Disciplinary Hinge*, the *Interdisciplinary* and the *Intervening Project*, with the latter two involving practitioners as research partners. We observed two strategies to successfully pursue academic qualifications within the projects' funding periods. First, one doctoral dissertation in each project explicitly targeted the collaboration with practitioners. Second, researchers were focusing their dissertations or habilitations on specific sub-questions with interdisciplinary orientation. Like for hypothesis 3, we found evidence for the *Interdisciplinary Project* that clear division of tasks among the research team, as well as purposeful combination of disciplinary, inter- and transdisciplinary project phases enabled the young researchers to conduct their research but also to fulfil other duties within the project, *e.g.* helping to prepare and implement transdisciplinary workshops. Moreover, several of the successful PhD and habilitation candidates in the *Interdisciplinary Project* gained new positions in academia.

5. Overall discussion and conclusion

In the past two decades, "new" modes of research, as advocated in the literature around 'post-normal science', 'mode 2′ knowledge production or 'transdisciplinarity' have made their way from postulation to practice. This study has operationalized the core claims found in the literature into five sets of hypotheses, aiming to test whether and to what extent diverse research modes as actually employed in sustainability-related research projects make a difference for both societal and academic outcomes.

Our combined quantitative and qualitative analysis of sustainability-related research projects finds supportive evidence for four of the six hypotheses on the link between (transdisciplinary) research mode and academic and societal outcomes. In particular, the trade-off between both kinds of outcomes, which has repeatedly been claimed in the literature (see Ruppert-Winkel et al. 2016), is materializing from our findings: While the involvement of practitioners in early project phases positively affects societal impacts (which confirms earlier findings by De Jong et al., 2016), practitioner involvement was found to negatively affect both academic publication output and citations. This pattern is replicated in the effect of the funding context: Whereas projects funded in mission-oriented contexts score higher on impacts and lower on publications and citations, the reverse is true for projects funded in bottom-up contexts. As well, PhD theses were found to be more likely completed in projects with less practitioner involvement.

Yet, while these findings are largely supported by the qualitative case examination, the in-depth study also allowed for insights into projects that produced both societally relevant knowledge with high societal impact and a strong publication and citation record. Hence, while the general patterns observed across the 81 cases point to a clear trade-off, the in-depth study demonstrates how such trade-offs can be avoided through careful project design and committed project management. These insights as well as the findings related to the role of the funding context suggest that a more nuanced perspective is needed for understaning the relation of "research mode" and societal as well as academic outcomes. More importantly, these insights suggest that impactful research may to a certain rely on certain design principles, such as the pointed involvement of non-academic actors (see *e.g.*Stauffacher et al., 2008). Further research will have to home in on such design choices and test to what extent they prove effective.

Two findings warrant closer inspection. First, we do not find a generally positive influence of practitioner involvement on societal outcomes but rather highly selective links. On the one hand, societal outcomes could be explained by early involvement of practitioners, but not by other aspects of involvement such as decision-making and value or knowledge contributions; on the other hand, the effect is only on the depth of impact and on media response, but not on impacts measured through diversity of sectors and geographical scales. However, considering the necessarily limited ambitions of projects, it may seem little surprising that projects which aim, for example, at local solutions, involving local practitioners, do not exhibit global impacts.

The second concerns our finding that involving practitioner knowledge not only does not foster societal outcomes, it also negatively affects academic publication outputs and citations. This stands in stark contrast with the finding that structured methods to integrate academic and non-academic knowledge emerges as a significant predictor of publication output. Two explanations come to our mind: On the one hand it appears plausible that the structured methods of knowledge integration employed in the studied projects also served to integrate different kinds of academic knowledge (regardless of their function to also integrate non-academic knowledge), hence the positive effect on academic outcomes. On the other hand, one could also speculate that researchers who employ structured knowledge integration methods tend to place much emphasis on the systematic production of knowledge and through this are more interested in strong academic outcomes.

While arguably one of the most comprehensive comparative analyses of research modes and their outcomes, this study is limited in various ways. It is restricted to sustainability-oriented projects in Germany. Funding structures and actual employment of research modes will differ in other national or international contexts. Many key variables rely on self-reported assessments. While this may introduce a bias towards 'success', it should not distort the dataset. For reasons of confidentiality, our research also does not allow to assess or compare

[5] 22 interviewees skipped this relatively complex part of the questionnaire or did not fully respond. From the remaining 59 projects, 17 did not involve PhD researchers.

individual projects. Our aim was to find general patterns and mechanisms at work across cases.

Three lines of inquiry appear relevant for further research. On a *conceptual* level, we found it difficult to clearly distinguish between applied research that involves practitioners and transdisciplinary research. Similarly, the notion of “empowering” participants by involving them into research, as found in much of the literature (*e.g.*Brandt et al., 2013), appeared ill suited to contexts where practitioners collaborated with researchers in an equal manner or where projects were even led by practitioners.

On an *empirical* level, we would encourage fellow researchers to continue on the path of comparative analysis, with particular emphasis to the “trade-off hypothesis”: Under which conditions is research likely to produce both strong societally and academically relevant outcomes?

Finally, our study was restricted to study research *projects,* typically lasting a few years only. However, the building of trustful academic-practitioner relationships and networks, which is so often advocated with regards to transdisciplinary research, is likely to need more time. Future research should look at more long-lasting academic-practitioner interactions and at the outcomes this produces over time.

Acknowledgements

We would like to thank the members of our advisory group, Antonietta di Giulio, Rico Defila, Michael Pregernig, Arnim Wiek and Michael Stauffacher, for their constructive and valuable feedback in early stages of this research; the German Research Foundation for providing the funding for the research project “Modes of sustainability-related research in comparison (MONA): Modes of research and their impact on scientific and societal project outcomes” under grant numbers NE1207/4-1 to Jens Newig and LA3024/1-1 to Daniel J. Lang; staff from the German Research Foundation and the German Federal Ministry of Education and Research for their support in preparing the data collection; project heads, researchers and practitioners involved in the investigated sustainability-oriented research projects for providing us with project documents, as well as for participating in a survey and semi-structured interviews; our student assistants Marie Josefine Hintz, Marie Weiß, Marion Blome, Sophia Schönig, Maria Brück, Silke Bölts, Alina Langkau, Franziska Steinbrügge, Jakob Wondra and Inga Melchior for their long-term and outstanding support with regard to data collection and data editing in preparation for this article.

References

Basco-Carrera, L., Warren, A., van Beek, E., Jonoski, A., Giardino, A., 2017. Collaborative modelling or participatory modelling? A framework for water resources management. Environ. Model. Softw. 91, 95–110.
Bergmann, M., Jahn, T., Knobloch, T., Krohn, W., Pohl, C., Schramm, E., 2012. Methods for Transdisciplinary Research: a Primer for Practice (Campus Verlag).
Bergmann, M., Brohmann, B., Hoffmann, E., Loibl, M.C., Rehaag, R., Schramm, E., Voß, J.P., 2005. Quality criteria of transdisciplinary research. A Guide for the Formative Evaluation of Research Projects. Institute for Social-Ecological Research, Frankfurt a.M.
Blatter, J., Haverland, M., 2012. Designing Case Studies: Exploratory Approaches in Small-N Research. Palgrave Macmillan, New York.
Bogner, A., Kastenhofer, K., Torgersen, H., 2010. In: In: Bora, A., Maasen, S., Reinhardt, C., Wehling, P. (Eds.), Inter- Und Transdisziplinarität Im Wandel? Neue Perspektiven Auf Problemorientierte Forschung Und Politikberatung 4 Wissenschafts- und Technikforschung. Baden-Baden, Nomos.
Brandt, P., Ernst, A., Gralla, F., Luederitz, C., Lang, D.J., Newig, J., Reinert, F., Abson, D.J., Von Wehrden, H., 2013. 'A review of transdisciplinary research in sustainability science. Ecol. Econ. 92, 1–15.
De Jong, S.P.L., Wardenaar, T., Horlings, E., 2016. 'Exploring the promises of transdisciplinary research: a quantitative study of two climate research programmes. Res. Policy 45 (7), 1397–1409.
Enengel, B., Muhar, A., Penker, M., Freyer, B., Drlik, S., Ritter, F., 2012. 'Co-production of knowledge in transdisciplinary doctoral theses on landscape development - an analysis of actor roles and knowledge types in different research phases. Landsc. Urban Plan. 105 (1–2), 106–117.
Fazey, I., Bunse, L., Msika, J., Pinke, M., Preedy, K., Evely, A.C., Lambert, E., Hastings, E., Morris, S., Reed, M.S., 2014. 'Evaluating knowledge exchange in interdisciplinary and multi-stakeholder research. Glob. Environ. Chang. Part A 25 (1), 204–220.
Funtowicz, S.O., Ravetz, J.R., 1993. 'SCience for the post-normal age. Futures 25 (7), 739–755.
Haider, L.J., Hentati-Sundberg, J., Giusti, M., Goodness, J., Hamann, M., Masterson, V.A., Meacham, M., Merrie, A., Ospina, D., Schill, C., Sinare, H., 2018. 'The undisciplinary journey: early-career perspectives in sustainability science. Sustain. Sci. 13 (1), 191–204.
Hall, K.L., Vogel, A.L., Huang, G.C., Serrano, K.J., Rice, E.L., Tsakraklides, S.P., Fiore, S.M., 2018. 'The science of team science: a review of the empirical evidence and research gaps on collaboration in science. Am. Psychol. 73 (4), 532–548.
Hansson, S., Polk, M., 2018. 'Assessing the impact of transdisciplinary research: the usefulness of relevance, credibility, and legitimacy for understanding the link between process and impact. Res. Eval. 27 (2), 132–144.
Hirsch Hadorn, G., Hoffmann-Riem, H., Biber-Klemm, S., Grossenbacher-Mansuy, W., Joye, D., Pohl, C., Wiesmann, U., Zemp, E. (Eds.), 2008. Handbook of Transdisciplinary Research. Springer.
Jahn, T., Bergmann, M., Keil, F., 2012. 'Transdisciplinarity: between mainstreaming and marginalization. Ecol. Econ. 79, 1–10.
Kueffer, C., Hirsch Hadorn, G., Bammer, G., van Kerkhoff, L., Pohl, C., 2007. 'Towards a publication culture in transdisciplinary research. GAIA 16 (1), 22–26.
Lang, D.J., Wiek, A., Bergmann, M., Stauffacher, M., Martens, P., Moll, P., Swilling, M., Thomas, C.J., 2012. 'Transdisciplinary research in sustainability science: practice, principles, and challenges. Sustain. Sci. 7 (1), 25–43.
Mahoney, J., 2012. 'The logic of process tracing tests in the social sciences. Sociol. Methods Res. 41 (4), 570–597.
Nowotny, H., Scott, P., Gibbons, M., 2004.) Re-thinking Science. Knowledge and the Public in an Age of Uncertainty. Polity Press, Oxford.
Phillipson, J., Lowe, P., Proctor, A., Ruto, E., 2012. 'STakeholder engagement and knowledge exchange in environmental research. J. Environ. Manage. 95 (1), 56–65.
Polk, M., 2014. Achieving the promise of transdisciplinarity: a critical exploration of the relationship between transdisciplinary research and societal problem solving. Sustain. Sci. 9 (4), 439–451.
Ruppert-Winkel, C., Arlinghaus, R., Deppisch, S., Eisenack, K., Gottschlich, D., Hirschl, B., Matzdorf, B., Mölders, T., Padmanabhan, M., Selbmann, K., Ziegler, R., Plieninger, T., 2015. Characteristics, emerging needs, and challenges of transdisciplinary sustainability science: experiences from the german social-ecological research program. Ecol. Soc. 20 (3).
Scholz, R.W., Tietje, O., 2002. Embedded Case Study Method: Integrating Quantitative and Qualitative Knowledge. Thousand Oaks, Calif.Sage.
Sheppard, S.R.J., Shaw, A., Flanders, D., Burch, S., Wiek, A., Carmichael, J., Robinson, J., Cohen, S., 2011. Future visioning of local climate change: a framework for community engagement and planning with scenarios and visualisation. Futures 43 (4), 400–412.
Stauffacher, M., Flüeler, T., Krütli, P., Scholz, R., 2008. Analytic and dynamic approach to collaboration: a transdisciplinary case study on sustainable landscape development in a swiss prealpine region. Syst. Pract. Action Res. 21 (6), 409–422.
Vera, C., 2018. Farmers transformed how we investigate climate. Nature 562 (7725), 9.
Walter, A., Scholz, R., 2007. Critical success conditions of collaborative methods: a comparative evaluation of transport planning projects. Transportation 34 (2), 195–212.
Weingart, P., 2008. How robust Is “Socially robust knowledge”? In: Carrier, M., Howard, D., Kourany, J. (Eds.), The Challenge of the Social and the Pressure of Practice: Science and Values Revisited. University of Pittsburgh Press, Pittsburgh, PA, pp. 131–145.
Wiek, A., Talwar, S., O'Shea, M., Robinson, J., 2014. Toward a methodological scheme for capturing societal effects of participatory sustainability research. Res. Eval. 23 (2), 117–132.
Wiek, A., Lang, D.J., 2016. Transformational sustainability research methodology. In: Heinrichs, H., Martens, P., Michelsen, G., Wiek, A. (Eds.), Sustainability Science SE - 3. CHAP, Springer, Netherlands, pp. 31–41.
Zscheischler, J., Rogga, S., 2015. Transdisciplinarity in land use science - A review of concepts, empirical findings and current practices. Futures 65 (1), 28–44.

Forest Policy and Economics 111 (2020) 102076

Contents lists available at ScienceDirect

Forest Policy and Economics

journal homepage: www.elsevier.com/locate/forpol

German forest management stakeholders at the science-society interface: Their views on problem definition, knowledge production and research utilization

Nataly Juerges[a,*], Stephanie Jahn[b]

[a] Department of Forest and Nature Conservation Policy, Georg-August-University Göttingen, Germany
[b] Research Group Governance and Sustainability, Leuphana University Lüneburg, Germany

ARTICLE INFO

Keywords:
Germany
Knowledge transfer
Participation
Sustainability research
Research policy
Transdisciplinarity

ABSTRACT

Facing ever more pressing global environmental problems, applied sciences like forest research are expected to benefit society beyond the mere production of new knowledge. However, newly gained scientific knowledge is often not brought into practical application. While scholarly conceptualizations on how to design the science-society interface accordingly have been widely discussed in academia, little attention has been paid to the stakeholders' views thereof.

Hence, this paper systematically compares the core assumptions of "normal science“, political use of scientific knowledge and transdisciplinary research with statements from interviews with 21 forest management stakeholders about their experiences and views on knowledge production and exchange in German forest research along the lines of problem definition, knowledge production and research utilization.

Our analysis finds that the assumptions of the conceptualization of political use of scientific knowledge have the most support through aligning stakeholder statements from the interviews, as stakeholders opt for a clear separation of science and practice in the phase of knowledge production. Furthermore, interviewees raised concerns about biased knowledge and strategic knowledge use in other actors on the one hand, while at the same time describing their own opportunistic use of knowledge. Fewer stakeholder statements aligned with the assumptions of transdisciplinary research, highlighting exchanges with other actor groups and mutual learning. But one key aspect of transdisciplinary research, the involvement of stakeholders in the problem definition, found a strong correspondence in the interviewees' statements.

Our explorative but systematic results demonstrate that no scholarly conceptualization is a panacea to maximize the effectiveness of the science-society interface. Rather, it illustrates how the clarification of scholarly and stakeholder conceptualizations can deliver levers to shape a more productive science-society interface in forest research.

1. Introduction

By acknowledging the pressing problems of global environmental change, applied sciences – such as forest research – are expected to benefit society beyond the mere production of new scientific knowledge (Beland Lindahl and Westholm, 2014; Maasen and Weingart, 2005). While many scholars fail to apply their societally relevant knowledge (Krott and Suda, 2007), many precious findings remain unnoticed by stakeholders (Krott and Suda, 2007; Böcher and Krott, 2014). On the contrary, stakeholders do not always acquire the scientific knowledge they need to solve their forest management problems (Salomaa et al., 2016). This mismatch between producers and users of scientific knowledge constrains the solution of urgent sustainability problems of our time.

In trying to bridge this research-implementation gap and restructuring the science-society interface, new forms of research have been established in forest research in recent years, exploring new pathways of knowledge exchange, and involving stakeholders in the research processes (Enengel et al., 2012; Brandt et al., 2013; Böcher and Krott, 2014; Klenk and Wyatt, 2015). While there is a substantial body of literature that conceptualizes these research approaches from the scholarly perspective (Van Kerkhoff and Lebel, 2006; Lang et al., 2012; Pregernig, 2014), little is known about the views of stakeholders on knowledge production and use at the science-society interface

* Corresponding author at: Department of Forest and Nature Conservation Policy, Georg-August-University Göttingen, Büsgenweg 3, 37077 Göttingen, Germany.
E-mail address: nataly.juerges@uni-goettingen.de (N. Juerges).

https://doi.org/10.1016/j.forpol.2019.102076
Received 11 July 2018; Received in revised form 14 November 2019; Accepted 25 November 2019

(Zscheischler and Rogga, 2015).

Earlier research investigating stakeholders at the science-society interface identified a couple of influencing factors for research utilization, like the practical salience of scientific results (Clark et al. 2016), the notion that research may be biased in support of another stakeholder group´s agenda or strategic use of knowledge (Grundmann, 2009; Steffek, 2009; Giessen et al., 2009; Posner et al., 2015) and heterogeneous capacities and engagement of stakeholders in the search and use of scientific information (Salomaa et al., 2016). Nevertheless, no study so far has systematically compared stakeholders' experiences, impressions and opinions against scholarly conceptualizations of the science-society interface so as to identify agreements or mismatches between science and society that hinder the effectiveness of the science-society interface.

To integrate both and thereby deliver a holistic perspective, we isolated the underlying assumptions of three different scholarly conceptualizations of the science-society interface (*normal science*, *political use of scientific knowledge* and *transdisciplinary research*) advocated in forest research and compared them systematically with interview material on the experiences, impressions and opinions of forest management stakeholders involved in integrative research settings.

Specifically, we examined three questions[1]:

1) How do the scholarly conceptualizations of *normal science*, *political use of scientific knowledge* and *transdisciplinary research* describe the science-society interface?
2) What experiences, impressions and opinions do forest management stakeholders have with regard to the science-society interface of forest research, and specifically concerning the agency of problem definition, the agency of knowledge production and research utilization?
3) How does the empirical data from our interviews align with the assumptions of the three different scholarly conceptualizations of the science-society interface?

2. Background: German forest research

A look at the history of German forest research illustrates some additional dynamics behind this research-implementation gap: Germany has a pioneering role in the development of forest science and silviculture (Fernow, 1911). Forestry science is an interdisciplinary, well-established scientific research discipline in Germany, uniting researchers with different types of expertise (Goodwin, 2011), such as inventory, hydrology, soil sciences, botany, zoology, business management, policy or law.

Traditionally, forest researchers, forest practitioners, and forest policy makers constituted a closed actor network. The close relationship between forest researchers and policy makers allowed long-term cooperation and informal knowledge transfer between research and decision makers (Morisse-Schilbach and Werland, 2009). Until the 1980s, German forest policy making was dominated by forestry lobby organizations that shared the perspective of forest practitioners and forest policy makers on the production function of forests (Juerges and Newig, 2015). Close relations existed also between forest administrations and forestry research organizations (Goodwin, 2011). This closed knowledge system was characterized by a widely shared normative understanding of what the forest is, what its functions are, and how it should be treated (Morisse-Schilbach and Werland, 2009).

Scientific support of forest policy making and forestry practice was always an important aspect of forestry sciences (Krott and Suda, 2007; Goodwin, 2011). However, a trade-off between close cooperation with practitioners, on the one hand, and a high reputation within the scientific community on the other, has been diagnosed. This is because of limited resources, which make it impossible to do both at a high level (Wagner, 2007). Goodwin (2011) examined how German forestry researchers communicate their findings to the media, citizens, policy makers and forestry practitioners. He showed that most researchers target their communication at other scientists, but do not completely neglect activities that target other groups. In the study, German forestry researchers argued that other researchers could be more proactive in the communication of new scientific knowledge to non-scientists. However, they also stated that sufficient resources would be not available for public relations and other knowledge transfer activities (Goodwin, 2011).

Motivated by strong incentives from universities and research organizations for faculty and individual researchers, in recent years many German forest scientists have focused increasingly on publishing in international peer-reviewed journals, instead of publishing in applied journals in German language, which forest stakeholders also read. This development has resulted in the closing down of some applied forest journals in the German language (e.g. Forstarchiv in 2017). Additionally, the increasing share of third party funding, combined with less public funding for permanent researcher positions, is contributing to stronger fluctuations of personnel within research organizations and a large share of short-term projects, making long-term relations with stakeholder more difficult to maintain.

International policy processes, such as biodiversity and climate change, have increasingly influenced forestry research. In this context, a dichotomy has developed between stakeholders and researchers interested mainly in ecological forest functions versus actors whose main interest are economic forest functions. As a result of the Rio Earth Summit in 1992, non-governmental organizations (NGOs) became increasingly important in forest policy. NGOs that focused on ecological forest concerns became ever more involved in German forest policy making (Juerges and Newig, 2015). These new stakeholders were also influencing forest research. Furthermore, new research institutes were funded that explicitly focused on environmental research (e.g. the Ökoinstitut or the Helmholtz Centre for Environmental Research). These new research institutes also conducted forest-related research and competed against established forest research institutes for third-party funding related to forest ecosystems. Thus, a divide between forestry research and forest-related nature and environmental research developed in the last decades, and no closed knowledge community exists anymore (Morisse-Schilbach and Werland, 2009). The opening up of this formerly closed knowledge community made communication with the forestry sector harder but contributed to the enhancement of communication with other important stakeholders. High quality research requires attention to the range of issues and interests in forests, not only to the needs and to the interests of the forestry sector. Therefore, the opening up of the formerly closed knowledge community is a positive development, though it requires new strategies for cooperation between science and practice.

3. Theoretical conceptualizations of the science-society interface

In order to systematically analyze scholarly perceptions of the science-society interface, we chose three conceptualizations – *normal science*, *political use of scientific knowledge* and *transdisciplinary research* – because of their active application and continuous discussion in in the fields of environmental and forest research (e.g. Pregernig, 2000; Kleinschmit et al., 2009; Moll and Zander, 2013; Beland Lindahl and Westholm, 2014; Böcher and Krott, 2014; Winkel et al., 2015; Salomaa et al., 2016; Reed and Meagher, 2019.) The differences and the intersections between these three offer potential for systematic juxtaposition with the stakeholders views. The boundaries between the three conceptualizations are not as sharp in the literature as outlined in this

[1] In this paper, we define stakeholder broadly, referring to those actors and organizations that have an interest in forests, either directly or indirectly (Freeman, 2010). We refer to agency as the authority of actors to prescribe actions (Biermann et al., 2012).

paper and there certainly are overlaps and hybrid forms. We do not claim our compilation to be comprehensive, but the description of the three conceptualizations follows a thorough narrative literature review based on data base search and reverse snowballing (Green et al., 2006).

3.1. Normal science

The concept of *normal science* describes a linear model of knowledge transfer that is often used as an antitype of new modes of knowledge production to illustrate the features of new visions of the ways in which science and society can interact more productively (e.g. Funtowicz and Ravetz, 1993; Gibbons, 1999; Pregernig, 2014).

The linear model of knowledge transfer assumes a direct flow of information from science to other societal subsystems – especially the policy sector – where scholarly knowledge is applied or leads to action: "(…) the interaction between science and politics is conceived of as one-dimensional, linear, and one-way: from science to policy ("truth speaks to power"). (…) It can be characterized by the position that knowledge is a necessary (if not sufficient) basis for decision-making" (Beck, 2011, p. 298). Thus, scholarly advice is assumed to lead to "efficiency and effectiveness" of "practical decisions" and "increased effectiveness and rationalization of political action" (Pregernig, 2014, p. 3643).

A further underlying assumption of *normal science* is that knowledge production is performed exclusively within academia and that scientific research leads to clear and unambiguous information (Beck, 2011; Grundmann, 2009). Moreover, it assumes that the receiving actors from outside academia are capable and willing to process scientific knowledge and are capable and willing to use this knowledge to find the best solutions possible (Böcher and Krott, 2014).

3.2. Political use of scientific knowledge

Political decision-making based on scientific knowledge is perceived as a necessity in modern societies (Sanderson, 2002; Kleinschmit et al., 2009). Policy makers increasingly rely on scientific expert advice (Maasen and Weingart, 2005; Boaz et al., 2019) to find solutions and to legitimize policies (Sanderson, 2002; Giessen et al., 2009). Questions concerning environmental sustainability problems, like those in forest management, are said to particularly profit from scientific expertise (Van Kerkhoff and Lebel, 2006; Böcher, 2008). The scientific conceptualizations behind this knowledge utilization process at the science-society interface can be subsumed under the label *political use of scientific knowledge*. Like in *normal science*, *political use of scientific knowledge* is based on an understanding of science and politics as two distinct societal subsystems with different codes and aims. However, the relationship between those subsystems is described as being coupled (Maasen and Weingart, 2005). Mechanisms exist that link the independent subsystems in order to use scientific knowledge in the political sphere: Linked by a unidirectional information flow from science to users, scientific insight needs to be transferred and translated so as to be used in practice (Van Kerkhoff and Lebel, 2006). To make sense of science in policy and politics, intermediary actors (Jasanoff, 2009), like knowledge brokers (Pielke Jr, 2007) or intermediary institutions (Lentsch and Weingart, 2011), are promoted. Although more integrative interactions around the concept of the political use of knowledge have been developed (Van Kerkhoff and Lebel, 2006; Reed and Meagher, 2019), the agency of science as single provider of knowledge remains unquestioned. In turn, the agency of problem definition is assumed to lie on the side of scholars if political stakeholders utilize scientific results that have already been generated/produced by independent research (Van Kerkhoff and Lebel, 2006; Giessen et al., 2009). On the other hand, science is societally embedded and research is also performed on behalf of specific questions by political institutions. In this case, the agency defining the research questions is closer to the side of the research utilizers (Van Kerkhoff and Lebel, 2006).

When it comes to assumptions about the actual use of scientific knowledge, various dangers are discussed: Giessen et al., 2009 mention the possibility of technocratic decisions made without deliberation and without legitimization by public discourse. Further concerns have been raised about an interest-led utilization of knowledge (Grundmann, 2009; Lund et al., 2009; Lövbrand, 2009). Furthermore, it has been observed that weaker societal groups have fewer resources to access scientific information. The political use of knowledge of stronger interest groups therefore confers privileges, creates power asymmetries, and the exclusion of weak actors (Steffek, 2009; Lövbrand, 2009; Ojha et al., 2009).

3.3. Transdisciplinary research

Challenging *normal science* and concepts of *political use of scientific knowledge*, *transdisciplinary research* has formed a strong research community within academia and is a serious attempt to open up science for society, aiming to tackle problems that range from the local to the global (Lang et al., 2012; Brandt et al., 2013; Zscheischler and Rogga, 2015). This new vision to advance the exchange processes at the science-society interface came to life in the mid-90s under the labels "mode 2" (Gibbons et al., 1995; Nowotny et al., 2001), "post normal science" (Funtowicz and Ravetz, 1993) and "transdisciplinarity" (Scholz et al., 2006)[2].

The expectation behind these new forms of research is that extensive involvement of actors from outside academia (for instance practitioners, politicians, business, civil society or NGOs) in research processes will lead to better or "more socially robust" knowledge (Nowotny, 1999). Therefore, this knowledge will be more likely to be applied and will eventually be more successful in solving societal problems (Funtowicz and Ravetz, 1993; Scholz et al., 2006; Lang et al., 2012; Miller et al., 2014).

The core argument of transdisciplinary research goes back to Weinberg, who observed that real-world problems transcend disciplinary and even academic boundaries. Therefore, diverse types of knowledge need to be taken into account to solve them (Weinberg, 1972), not only scholarly expertise. Consequently, *transdisciplinary research* calls for scientists and stakeholders to produce societally robust knowledge jointly (Gibbons, 1999; Kates et al., 2001; Nowotny et al., 2001) by actively involving stakeholders from outside academia into research processes at various stages (Stauffacher et al., 2008). Multiple concepts describe the involvement of stakeholders in research processes in the realm of transdisciplinarity: knowledge exchange (Fazey et al., 2013), knowledge integration (Bergmann et al., 2012; Defila and Di Giulio, 2015), co-production (Pohl et al., 2010; Polk, 2015), co-creation (Polk, 2015), mutual learning (Scholz et al., 2000), (different degrees of) collaboration (Stauffacher et al., 2008).

Unlike in *normal science* – where research problems are defined while enclosed inside the scholarly community – *transdisciplinary research* focuses on "real-world problems" from the very start of the research process: In the ideal case these societal problems are explored and described by scientists and stakeholders jointly (Jahn et al., 2012). Moreover, the aim of *transdisciplinary research* is not only to produce analytical knowledge, but to "go beyond problem analysis" (Lang et al., 2012), initiate practical action and find applicable solutions to real world problems (Miller et al., 2014). Therefore, transdisciplinarity has a strong functional component (Nowotny, 1999; Miller et al., 2014), but it also entails a democratic one (Enengel et al., 2012; Polk, 2014; Klenk and Wyatt, 2015) that emphasizes that actors from outside academia have the right to participate in solving sustainability problems or even that they should be empowered to solve these (Stauffacher et al., 2008).

[2] Other related concepts not discussed in this article are action research (Lewin, 1946) and participatory research (e.g. Suda et al., 2003).

Table 1
Comparison of the underlying assumptions of the research concepts analyzed.

Conceptual differences	"Normal" science	Political use of scientific knowledge	Transdisciplinary research
Problem definition	*Agency of problem definition located solely with scholars:* – Research process exclusively performed within the scientific system and clearly separated from other societal systems and their logic (Jasanoff, 1987; Cash, 2003) – As research is "removed from considerations of application" (Grundmann, 2009: 398) the agency of problem definition lies solely within academia and with scholars	*Agency of problem definition is located either solely on the side of stakeholders or solely on the side of scholars:* – If stakeholders utilize scientific results that have been generated previously and independently, the agency of problem definition lies with academia (Van Kerkhoff and Lebel, 2006; Giessen et al., 2009) – If research is performed on behalf of specific questions of, e.g., political institutions, the agency of problem definition lies with the corresponding stakeholders (Van Kerkhoff and Lebel, 2006)	*Agency of problem definition located with scholars and stakeholders equally:* – Explicit focus on "real-world-problems" (Jahn et al., 2012). – Joint problem definition is the key characteristic of many conceptualizations of transdisciplinary research activities (e.g. Jahn et al., 2012; Lang et al., 2012)
Knowledge production	*Agency of knowledge production located solely within academia:* – Information flow between science and other societal systems either neglected (two-communities hypothesis) or conceptualized as unidirectional information flow from science to society (Pregernig, 2014) – Knowledge production performed exclusively within academia, scientific research leads to clear and unambiguous information (Beck, 2011)	*Agency of knowledge production located solely within academia:* – Science and politics assumed to be distinct societal subsystems (Maasen and Weingart, 2005) – Science seen as a subsystem where knowledge is produced; politics seen as a subsystem where knowledge is utilized (Maasen and Weingart, 2005; Sanderson, 2002; Kleinschmit et al., 2009)	*Agency of knowledge production shared by scholars and stakeholders interactively:* – Active involvement of stakeholders in the research process at different stages (Stauffacher et al., 2008; Belcher et al., 2013). – The goal of transdisciplinarity is shared knowledge production by scientists and stakeholders (Gibbons, 1999; Kates et al., 2001; Nowotny et al., 2001)
Potentials for research utilization by stakeholders	*Agency of research utilization is located solely with the stakeholders:* – Knowledge is produced as basic research and is detached from considerations of application (Grundmann, 2009) – "Two communities" thesis negates the practical application of scientific information to new societal solutions (Pregernig, 2014) – The linear model assumes a direct and perfect application of scientific information in stakeholders' solution-finding without considering barriers in the information flow from science to practice (Pregernig, 2014)	*Knowledge produced by scholars is of value for society; it´s utilization by stakeholders needs knowledge transfer, while also risks of research utilization are discussed:* – Modern societies are increasingly dependent on scientific "evidence" for decision-making (Sanderson, 2002; Maasen and Weingart, 2005; Böcher, 2008) – Subsystems of science and politics are coupled by unidirectional information flow from science to politics, supported by intermediary actors (Jasanoff, 2009; Pielke Jr, 2007) and/or intermediary institutions (Lentsch and Weingart, 2011) – Concerns about technocratic decisions, selection and interests leading the use of knowledge, and the exclusion of weak stakeholder groups (Giessen et al., 2009; Grundmann, 2009; Steffek, 2009; Lund et al., 2009; Lövbrand, 2009)	*Joint efforts of scholars and stakeholders are assumed to help with the solution of real world problems:* – New knowledge – created by scholars and stakeholders jointly – will be (more) accepted by stakeholders and therefore knowledge will be more likely utilized by stakeholders in the practice field (Nowotny, 1999: Funtowicz and Ravetz, 1993; Lang et al., 2012; Miller et al., 2014; Scholz et al., 2006)

Table 2
Interview participants.

Actor types	Actor affiliation	Number of interviewees
National level, Germany	*Forestry NGO* Civil society actor representing economic interests	2
	Environmental NGO Civil society actor representing ecological interests	3
	Environmental administration Governmental actor with ecological interests	1
	Outdoor Recreation NGO Civil society actor representing social and economic interests	1
	Timber industry representative Market actor with economic interests	1
	Employee NGO Civil society actor representing social and economic interests	1
State level, Bavaria	*Forestry NGO* Civil society actor representing economic interests	2
	Environmental protection NGOs Civil society actors representing ecological interests	2
Local/regional level, Augsburg	*Town forester* Governmental actor with interest in balancing ecological, social, and economic interests	1
	Small-scale forest owner cooperative Market actor	1
	State forest service members Governmental actor with mainly economic interests	2
	Forest administration Governmental actor interest in balancing ecological, social, and economic interests	1
	Touristic organization Civil society actor representing economic interests	1
	Environmental NGO Civil society actor representing ecological interests	1
Interview participants in total		21

3.4. Commonalities and differences between the approaches

We identified within these approaches three major conceptual differences in their views of the science-society interface: (1) agency of problem definition, (2) agency of knowledge production, (3) the potentials of research utilization by stakeholders (Table 1).

4. Data and methods

The empirical data to compare the scholarly conceptualizations described above were collected in the context of the European Union (EU) funded project "ALTERFOR- Alternative models for future forest management". ALTERFOR is a large-scale, collaborative research project that involves twenty organizations from nine countries. Forest management concepts were evaluated for ten local case study areas representing different prevailing forest management practices and socio-ecological conditions in Europe. One of the German case studies was located in the state of Bavaria in the district of Augsburg. The interviews were conducted at the beginning of the project in July-August 2016. The interviews aimed to identify the interests that stakeholders have in ecosystem services provided by forest landscapes, prior experience stakeholders had with research, and what wishes and interests they had concerning the ALTERFOR project. We designed the interviews to fit the aims of the ALTERFOR project, thus, this paper is based on the "by-products", i.e. information that came up in that interviews.

First, a stakeholder analysis was conducted to identify stakeholders with an interest in forests at a national level, at the state level in the state of Bavaria, and in the district of Augsburg. The interviewee selection was guided by the goal of including stakeholders with different interests in forest ecosystems. The interviewee selection had the aim of ensuring that the perspectives of stakeholders from three different political-administrative levels were included, and that governmental actors, civil society and stakeholders with economic interests were represented. Most governmental actors were interviewed at the local level because the local public foresters and the local administration have far reaching competences for forest management in the area. In contrast, governmental actors at the state level are focusing on developing more general forest management guidelines in their work. Since forestry is in the political-administrative responsibility of the states in Germany, no national forest administration exists. In contrast, nature conservation is much more regulated at a national level and a national level environmental administration exists. In total, 21 interviewees participated in the interviews (Table 2).

The interviews were supported by an interview guide, which was developed by two researchers, based on the knowledge demand of the ALTERFOR project. Research documents from previous research projects and scientific literature were used to develop the interview guide. It included an initial section of questions related to forest ecosystem services, and a second part had questions related to experience with and impressions from research. Only the questions in the second part were used for this study. Specifically, the interviewees were asked the

Table 3
Types of experiences with forest research.

Types of experience with forest research	Experiences described by interview participants
Research utilization	Visiting the presentation of research projects Reading project summaries, project reports or publications
Passive involvement	Taking part in a survey Participation in an interview Participation in a stakeholder workshop Reviewing a research proposal
Active participation	Being an official partner within a research project (including financial participation) Providing infrastructure for a research project Implementation of own research project Having research experience based on possessing a Bachelor or Master's degree Previous employment as a researcher

following questions:

- Have you been involved in any kind of research project in the past?
- Could you explain to me what impressions and experiences you had during this or these research process(es)?
- How do you evaluate the benefit (German: Nutzen) of this process for the transfer of scientific findings into practice?
- Do you think knowledge transfer from science into practice could be somehow improved?
- How and with what measures could the transfer of scientific findings to practice be further improved?

The interview guide was pre-tested with the head of the stakeholder organization participating as a project partner in the ALTERFOR project. After this pre-test some questions were slightly modified to make the questions more clear. Questions were adjusted according to the experience of the interviewees. The interviews were fully recorded. The interviews lasted between 30 min and 2 h, with an average of 60 min. The interviews were transcribed in bullet points, relevant statement were transcribed verbatim.

Based on the contrasting conceptual assumptions about the science-society interface that we identified within our literature analysis, we developed a category system by deduction. The identified differences of the concepts presented in Section 2 served as analytical framework for our data analysis. Four main categories served to structure the data initially: (1) Prior experience with research, (2) views, experiences, and opinions about problem definition, (3) views, experience, and opinions on knowledge production, and (4) views, experience, and opinions on research utilization. The interview data has been coded thematically according to these categories in a qualitative content analysis (Glesne, 2006).

5. Stakeholder views on problem definition, knowledge production and research utilization

The interview participants had several different types of experience with research (Table 3).

Some interviewees said they did not have the time to participate in research. Instead, they were only utilizers of new knowledge, by visiting presentations of research projects or reading project summaries or reports.

Many interviewees stated that their main motivation to participate in different types of research was their personal interests in science, and not their believing that the participation would bring any direct advantages for their work. Participation in surveys, interviews or stakeholder workshops were described as being interesting and providing some variety in their jobs, in comparison to their usual tasks. In contrast, some interviewees also argued that participation in research can have direct advantages for their work and that results are sometimes directly applicable to their work.

Participation in workshops, surveys, or in qualitative interviews as an interviewee was often not considered to be participation in research. Instead, several interviewees only described those activities and situations in which they had a more active role in research (e.g. data collection as graduate students or previous employment in research organizations). Furthermore, several interviewees explained how their organization implemented an applied research project (e.g. grazing projects within forests). A spectrum of participation within research was identified in the descriptions of the interview participants, ranging from no participation in research at all to the implementation of an own research project.

5.1. The view on problem definition

In the following section we display the positions of the interviewees on problem definition in forest research. In this area, some interviewees criticized that research topics would often be too theoretical, without any direct use for them:

> "Sometimes I wish that other questions were examined, questions that have greater practical relevance. "
>
> (Town forester)

Some of the interviewees argued that research topics should be more applied and that researchers should have more interaction with stakeholders to learn about the most pressing problems and challenges in practice:

> "University employees become more and more distanced from practice the longer they work there; they should seek more actively to stay in touch with practical problems."
>
> (Employee of Environmental NGO, local level)

However, the stakeholders interviewed also argued that the definition of research aims and research questions were often driven by vested interests:

> "Research should examine issues more holistically; often a lot of factors are ignored, for example in carbon dioxide accounting, often only the vested interests of certain lobby groups are considered."
>
> (Employee of an environmental NGO, national level)

However, there were also a few stakeholders who did not criticize processes of problem definition in former research.

5.2. The view on the production of scientific knowledge

We analyzed how the interviewees perceived the relationship of scientists and stakeholders in the production of scientific knowledge. Interviewees preferred a clear differentiation between the tasks of researchers and stakeholders. Academia should be the producer of knowledge and carry out research projects. Stakeholders can help to identify relevant research questions, integrate new knowledge into practice, and implement new approaches:

> "I think that the role of practitioners in research projects is to identify problems and to help to implement solutions"
>
> (Employee of a forestry NGO, national level)

Some interviewees had experience with participation in transdisciplinary research projects. Positive and negative arguments about this experience were described in the interviews. An interview participant liked the participatory research process that she experienced because different interests were considered by the researchers, based on the stakeholder involvement:

> "My experiences with the participation of practitioners in research projects are all positive; this is always rewarding. Practitioners can put things in perspective"
>
> (Environmental administration, national level)

Another interviewee criticized that the stakeholder involvement processes that he experienced was too time-consuming, in relation to the output of the whole project. Furthermore, he argued that the outcome of the project was a mixture of all different positions, without any real use for anyone:

> "The participation processes that I participated in were usually rather abstract; usually things are discussed on a rather general level … the results are usually a mixture of all opinions and not very specific"
>
> (Timber industry representative, national level)

Most stakeholders argued that they would not have sufficient time resources to participate in research projects:

> "A general problem is that we and other practitioners do not have sufficient time and resources to get more involved"

(Environmental administration, national level)

Several interviewees called for a clear differentiation between research and practice by arguing that only independent researchers could come to conclusions that are not heavily influenced by the vested interests of enterprises or lobby groups. Several interviewees were critical of the involvement of market actors in research because this involvement would change the goals of research towards interest maximization for specific actors instead of welfare maximization of the whole of society. In this context, stakeholders criticized that forest research would often not be independent from vested interests:

> "I think it is a problem that projects are usually not neutral, instead there is an expected result that is pre-set; forestry research is often very normative."
>
> (Employee of an environmental NGO, national level)

5.3. The view on research utilization

The stakeholder views on the impact of new information reflect their experiences and opinions about how research insights are processed and how they lead to action – or not. For instance, interviewees from different lobby groups reported that they would take new research into account that supports the interests and arguments of their group. The lobby group members argued that their positions would have greater legitimacy and credibility if they were supported by new scientific literature. Thus, they refer to scientific studies and reports in their own publications and websites:

> "We refer often to scientific findings to increase our credibility, we try to support our arguments with scientific facts"
>
> (Employee of an environmental NGO, national level)

Some of the stakeholders interviewed argued that research that did not support their own arguments was incorrect and driven by the ideologies of other stakeholders. Other stakeholders did not question the reliability of unfavorable new scientific knowledge but argued that they would not refer to research findings that would question their own interests and positions. Furthermore, stakeholders argued that new information often has no impact on practice because of a lack of long-term communication strategies of new knowledge in practice:

> "Research projects often have no direct use for practitioners.... After the end of the research project the practical implications are not followed up; researchers are sometimes not even available anymore because they do no longer work at the research organization"
>
> (Employee of a forestry NGO, national level)

A forest owner representative argued that science would not offer any solutions to practical problems in forest management:

> "Based on my past experiences with research projects, they usually offer no benefit for practitioners. The results are too general and recommendations do not take the specific site conditions sufficiently into account; the knowledge of the local forest owner is not considered sufficiently"
>
> (Forest owner representative, state of Bavaria)

In contrast, a forester of the state forest service argued that new, scientific information and monitoring could help to create awareness within forest management:

> "Past studies had positive effects on forest use because we know much better which species occur in the area due to ecological research. Research makes it possible to raise awareness for certain topics, specifically in privately owned forests"
>
> (State forest service)

However, the interviewees saw major deficits in the integration of new knowledge into practice. They argued that more resources should be invested in the communication of new knowledge to stakeholders and that communication channels should be used that are easily accessible for stakeholders. Furthermore, methods of communication should be adapted more to the needs and abilities of stakeholders:

> "Much more time and money should be invested in the communication of research results to non-scientific actors…more simplifications should be possible…you need translators to transfer scientific finding into practice… You need guidelines, simple messages, a nice layout, checklists, a selection of the right media, tailored to the target group. And researchers should travel much more to the practitioners and present their findings there, locally"
>
> (Employee of a forestry NGO, national level)

The implementation of new knowledge by stakeholders has been described by the interviewees as being quite limited, for different reasons: unwillingness of some stakeholders to solve problems, lack of applicable problem-solving strategies, or the existence of powerful stakeholders with contradicting interests. For example, an interviewee argued:

> "New knowledge is always useful for practice but much is not implemented in practice because it is not feasible due to different interests and demands"
>
> (Town forester)

A state forester argued that sometimes the solutions suggested by researchers would be not realizable because they would require changes too substantial in structure and process, and which are therefore not possible to make. Several interviewees argued that new scientific knowledge has only an impact if it fits the existing preferences and goals of stakeholders. For example, an interviewee stated:

> "Often, decisions are based more on interests than on knowledge; issues and new knowledge are only transferred if they fit into a certain worldview, if new knowledge questions their own interests these findings are ignored"
>
> (Employee of a nature conservation organization, state of Bavaria)

Stakeholders argued that new strategies that promise higher financial returns or other advantages would be very likely implemented by practitioners:

> "For knowledge transfer it is important that projects have a practical relevance and that the results can be commercially used; something that has a financial profit is taken up by practitioners automatically"
>
> (Employee of a forestry NGO, national level)

6. Discussion

Overall, our interviewees expressed a great interest and a need to be asked by scientists what should be investigated. While *transdisciplinary research* highlights this, by involving stakeholders in the early phase of problem definition (Jahn et al., 2012), some initiatives that also follow the *concept of political use of knowledge* are guided by practical problems (Van Kerkhoff and Lebel, 2006; Giessen et al., 2009). In contrast to their strong interest in being involved in the definition of the problem, none of our interviewees explicitly articulated an interest in participating in knowledge production. Alingning most strongly with the *normal science* and *political use of scientific knowledge*, many expressed a preference for a clear separation between science and practice in knowledge production. These statments reflect the specific concept of "consulting transdisciplinarity" as introduced by Mobjörk (2010). Consulting transdisciplinarity is described as an approach where stakeholders "have the role of responding and reacting to the research conducted and researchers bear their thoughts and perspectives in mind during research" (Mobjörk, 2010: 870), but the degree to which they are involved into the knowledge production process remains limited.

Moreover, all stakeholders interviewed highlight the topic of terms and language: They argue for a clear and comprehensible language to help understanding at the science-society interface. This aspect has also been empirically observed earlier by Salomaa et al. (2016). While understandability is strongly problematized in the discourse on *political use of scientific knowledge* (Lentsch and Weingart, 2011; Jasanoff, 2009; Pielke Jr, 2007), in *transdisciplinary research* this issue is hidden in the claim for high-quality integration processes (Jahn et al., 2012; Lang et al., 2012).

On the one hand, many interviewees were very sensitive towards power structures and worried that research with stakeholder involvement could serve vested interests too much. They articulated assumptions of biased research that was conducted in favor of competing actor groups. Different stakeholder types, including governmental actors, civil society, and actors representing economic interests shared this concern. On the other hand, when it came to actual research utilization, some of the stakeholders interviewed displayed a strategic use of knowledge themselves. Pursuing their targets, interviewees saw science as a provider of arguments they could use selectively, in a goal-oriented way. If new scientific knowledge did not support their interests, they tended to ignore it. We observed this strategy mainly in interviewees who were representing interest groups, both with economic and ecological interests. Both of these aspects were also observed by earlier research (Clark et al., 2016; Posner et al., 2015; Grundmann, 2009; Lund et al., 2009 and Lövbrand, 2009; Green and Lund, 2015). Power issues have been discussed intensively in conceptualizations of the *political use of scientific knowledge* (Giessen et al., 2009), whereas in conceptualizations of *transdisciplinary research*, power dynamics seem to be neglected, as transdisciplinarity is assumed to be a process where actors from science and practice work together on equal footing (Nowotny, 1999; Pohl et al., 2010, Lang et al., 2012).

Aside from the more tactical stakeholders (mainly NGO members), other interviewees were less strategic (mainly governmental actors from forestry and environmental administrations). Instead, they were interested in mutual learning and exchange with other actor groups in the field, something that *transdisciplinary research* address strongly. Generally, it is important to highlight that experiences, impressions and opinions stated by our interviewees show a great heterogeneity. Like Salomaa et al., 2016, we observed differences in the stakeholders past experiences, openness versus pragmatism, knowledge level, their degree of engagement, time resources, and aims. These differences were based partially on their professional role, depending on whether stakeholders were NGO members, foresters, or part of the administration. Some interviewees mentioned time constraints as an important limitation for engaging in research. Thus, they want to get as much as possible for as little input as possible.

For the interpretation of the findings of this study, the context of our data collection needs to be taken into account. The qualitative interviews that we conducted to collect data, were designed for the purpose to fit the aims of the ALTERFOR project. The interview participants might have answered differently, if they would have been asked questions that explicitly probed the issues addressed in the research questions of this study and if the interviews had been announced as a study about stakeholder perception at the science-society interface instead of interviews at the beginning of a large-scale research project with stakeholder involvement. However, the context of the interviews might also have been an advantage, because interview participants were not asked to answer questions only theoretically. Instead, they were in the situation to articulate their expectations and wishes regarding knowledge exchange for an upcoming research project.

7. Conclusions

Although scholarly conceptualizations of the science-society interface are discussed widely in the scientific literature (Van Kerkhoff and Lebel, 2006; Lang et al., 2012; Pregernig, 2014), still little is known about the view of stakeholders on knowledge production and use at the science-society interface (Zscheischler and Rogga, 2015). Using *normal science* as a default setting, the concept of *political use of scientific knowledge* is centered on the translation, transfer and implementation of scientific research (Pielke Jr, 2007; Jasanoff, 2009; Böcher and Krott, 2014), while *transdisciplinary research* highlights the integrative, collaborative work of scholars and stakeholders (Lang et al., 2012). Our systematic comparison of these three scholarly conceptualizations revealed substantial differences in these approaches concerning the agency of problem definition, the agency of knowledge production and the potentials of research utilization by societal stakeholders. The concerns about strategic use of knowledge and resulting power asymmetries raised in literature about *political use of scientific knowledge* (Grundmann, 2009; Lövbrand, 2009; Lund et al., 2009; Ojha et al., 2009; Steffek, 2009) find many correspondents in the stakeholder statements. While stakeholders formulated no desire in being actively involved in knowledge production (as promoted in *transdisciplinary research*), they had a high interest in being involved in defining research problems. While *transdisciplinary research* takes this into account, conceptualizations about *political use of scientific knowledge* partly reject this claim and warn against the politicization of science (Maasen and Weingart, 2005). Stakeholders who are NGO members, and who engage daily in political struggles, have a conception of the science-society interface that is close to the concept of *political use of scientific knowledge*. In contrast, stakeholders who are less in involved in political processes are more interested in mutual learning, have a conception of the science-society interface that is more similar to the conceptual assumptions defining *transdisciplinary research*. The heterogeneity of stakeholders' cognitive, motivational and financial capacities to engage at the science-society interface is hardly discussed in all scholarly conceptualizations and this reflects the need to investigate stakeholder typologies more systematically.

Our empirical insights are illustrative, but they are derived from 21 stakeholder interviews only. This study does not present a representative typology of stakeholder experiences. Instead, we present the diversity of stakeholder views at the science-society interface. Accordingly, there is a need to investigate stakeholders' views of the science-society interface further and more intensively, in both depth and range. A quantitative follow-up study could help to develop a more detailed and generalizable typology of stakeholders. Moreover, German forest research has several characteristics that are different from other research fields. Forest-related stakeholders often have a high level of trust in forest researchers and a tradition of close cooperation between science and practice exists (Morisse-Schilbach and Werland, 2009; Goodwin, 2011). This allows for an easy establishment of stakeholder involvement in research projects. Therefore, it would be valuable to study whether our results are transferable to other research fields without an applied research tradition. However, the findings might also be transferable to other applied fields of life science, for example, agriculture research.

Bridging the knowledge-application gap remains a mayor challenge – not only the field in forest research. In regard to our findings, we propose for application-oriented scholars to clarify their own conceptualization of the science-society interface and to conduct stakeholder analyses (Reed et al., 2009; Leventon et al., 2016) in an early phase of the research process, so as to better address the stakeholders' capacities, interests and power resources and to create a more efficient science-society interface.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

This study was conducted within the EU-project, ALTERFOR. The project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 676754. We would like to thank all interviewed stakeholders for their participation in this study. Responsibility for the information and views set out in this article lies entirely with the authors.

Authors statement

Nataly Jürges: Conceptualization, Methodology, Investigation, Writing - Original Draft, Writing - Review & Editing, Projekt administration

Stephanie Jahn: Writing-Initial Draft, Investigation, Writing-Review & Editing.

References

Beck, S., 2011. Moving beyond the linear model of expertise? IPPC and the test of adaptation. Reg. Environ. Chang. 11, 297–306.
Beland Lindahl, K., Westholm, E., 2014. Transdisciplinarity in practice: aims, collaboration and integration in a Swedish research programme. J. Integr. Environ. Sci. 11 (3–4), 155–171.
Belcher, B., Rasmussen, K., Kemshaw, M., Zornes, D., 2013. Finding appropriate definitions and measures of research quality for transdisciplinary and applied natural resource management research: a systematic review protocol. In: Occasional Paper 99. CIFOR, Bogor, Indonesia.
Bergmann, M., Knobloch, T., Krohn, W., Pohl, C., Schramm, E., 2012. Methods for Transdisciplinary Research. A Primer for Practice. Campus, Frankfurt/New York.
Biermann, F., Abbott, K., Andresen, S., Bäckstrand, K., Bernstein, S., Betsill, M.M., Bulkeley, H., Cashore, B., Clapp, J., Folke, C., Gupta, A., Gupta, J., Haas, P.M., Jordan, A., Kanie, N., Kluvánková-Oravská, T.L., Lebel, L., Liverman, D., Meadowcroft, J., Mitchell, R.B., Newell, P., Oberthür, S., Olsson, L., Pattberg, P., Sánchez-Rodríguez, R., Schroeder, H., Underdal, A., Camargo Vieira, S., Vogel, C., Young, O.R., Brock, A., Zondervan, R., 2012. Navigating the Anthropocene: improving earth system governance. Science 335 (6074), 1306–1307.
Boaz, A., Davies, H., Fraser, A., Nutley, S., 2019. What works now? An introduction. In: Boaz, A., Davies, H., Fraser, A., Nutley, S. (Eds.), What Works Now? Evidence Informed Policy and Practice. Policy Press, Bristol.
Böcher, M., 2008. The role of scientific knowledge in public policy theory and in political practice – the case of integrated rural development. In: Stehr, N. (Ed.), Knowledge and Democracy – A 21st Century Perspective. Transaction Publishers, New Brunswick, pp. 243–261.
Böcher, M., Krott, M., 2014. The RIU model as an analytical framework for scientific knowledge transfer: the case of the "decision support system forest and climate change". Biodivers. Conserv. 23, 3641–3656.
Brandt, P., Ernst, A., Gralla, F., Luederitz, C., Lang, D.J., Newig, J., Reinert, F., Abson, D.J., von Wehrden, H., 2013. A review of transdisciplinary research in sustainability science. Ecol. Econ. 92, 1–15.
Cash, D.W., Clark, W.C., Alcock, F., Dickson, N.M., Eckley, N., Guston, D.H., Jäger, J., Mitchell, R.B., 2003. Knowledge systems for sustainable development. Proceedings of the national academy of sciences 100 (14), 8059–8061.
Clark, W.C., Tomich, T.P., Van Noordwijk, M., Guston, D., Catacutan, D., Dickson, N.M., McNie, E., 2016. Boundary work for sustainable development: Natural resource management at the Consultative Group on International Agricultural Research (CGIAR). Proceedings of the National Academy of Sciences 113 (17), 4615–4622.
Defila, R., Di Giulio, A., 2015. Integrating knowledge: challenges raised by the "Inventory of Synthesis". Futures 65, 123–135.
Enengel, B., Muhar, A., Penker, M., Freyer, B., Drlik, S., Ritter, F., 2012. Co-production of knowledge in transdisciplinary doctoral theses on landscape development – an analysis of actor roles and knowledge types in different research phases. Landsc. Urban Plan. 105, 106–117.
Fazey, I., Evely, A.C., Reed, M.S., Stringer, L.C., Kruijsen, J., White, P.C.L., Newsham, A., Jin, L., Cortazzi, M., Phillipson, J., Blackstock, K., Entwistle, N., Sheate, W., Armstrong, F., Blackmore, C., Fazey, J., Ingram, J., Gregson, J., Lowe, P., Morton, S., Trevitt, C., 2013. Knowledge exchange: a review and research agenda for environmental management. Environ. Conserv. 40 (1), 19–36.
Fernow, B.E., 1911. A Brief History of Forestry: In Europe, the United States and Other Countries. Toronto University Press, Cambridge, Mass.
Freeman, R.E., 2010. Strategic Management: A Stakeholder Approach. Cambridge University Press, Cambridge, Mass.
Funtowicz, S., Ravetz, R., 1993. Science for the post-normal age. Futures (September), 739–755.
Gibbons, M., 1999. Science's new social contract with society. Nature 402 (December), 81–84.
Gibbons, M., Limoges, C., Nowotny, H., Schwartzman, S., Scott, P., Trow, M., 1995. The new production of knowledge: the dynamics of science and research in contemporary societies. Contemp. Sociol. 24 (6).
Giessen, L., Kleinschmit, D., Böcher, M., 2009. Between power and legitimacy – discourse and expertise in forest and environmental governance. Forest Policy Econ. 11, 452–453.
Glesne, C., 2006. Becoming Qualitative Researchers. An introduction. Pearson Education, Boston.
Goodwin, B., 2011. Die Perspektive von Wissenschaftlern auf die Wissenschaftskommunikation am Beispiel deutscher Forstwissenschaftler. Technische Universität München, München Dissertation.
Green, K.E., Lund, J.F., 2015. The politics of expertise in participatory forestry: a case from Tanzania. Forest Policy and Economics 60, 27–34.
Green, B.N., Johnson, C.D., Adams, A., 2006. Writing narrative literature reviews for peer-reviewed journals: secrets of the trade. J. Chiropr. Med. 5 (3), 101–117.
Grundmann, R., 2009. The role of expertise in governance processes. Forest Policy Econ. 11, 398–403.
Jahn, T., Bergmann, M., Keil, F., 2012. Transdisciplinarity: between mainstreaming and marginalization. Ecol. Econ. 79, 1–10.
Jasanoff, S., 1987. Contested boundaries in policy-relevant science. Soc. Stud. Sci. 17 (2), 195–230.
Jasanoff, S., 2009. The Fifth Branch: Science Advisers as Policymakers. Harvard University Press, Cambridge.
Juerges, N., Newig, J., 2015. How interest groups adapt to the changing forest governance landscape in the EU: a case study from Germany. Forest Policy Econ. 50, 228–235.
Kates, R.W., Clark, W.C., Corell, R., Hall, J.M., Jaeger, C.C., Lowe, I., ... Iii, B.M., 2001. Sustainability science. Science 292 (5517), 641–642.
Kleinschmit, D., Böcher, M., Giessen, L., 2009. Discourse and expertise in forest and environmental governance – an overview. Forest Policy Econ. 11, 309–312.
Klenk, N.L., Wyatt, S., 2015. The design and management of multi-stakeholder research networks to maximize knowledge mobilization and innovation opportunities in the forest sector. Forest Policy Econ. 61, 77–86.
Krott, M., Suda, M., 2007. Spuren im Politikfeld hinterlassen. In: Krott, M., Suda, M. (Eds.), Macht Wissenschaft Politik? Aspekte wissenschaftlicher Beratung im Politikfeld Wald und Umwelt. Springer VS, Wiesbaden.
Lang, D.J., Wiek, A., Bergmann, M., Stauffacher, M., Martens, P., Moll, P., Swilling, M., Thomas, C.J., 2012. Transdisciplinary research in sustainability science: practice, principles, and challenges. Sustain. Sci. 7 (Supplement 1), 25–43.
Lentsch, J., Weingart, P., 2011. In: Lentsch, J., Weingart, P. (Eds.), Introduction: the quest for quality as a challenge to scientific policy advice: an overdue debate? Cambridge University Press, Cambridge.
Leventon, J., Fleskens, L., Claringbould, H., Schwilch, G., Hessel, R., 2016. An applied methodology for stakeholder identification in transdisciplinary research. Sustain. Sci. 11 (5), 763–775.
Lewin, K., 1946. Action research and minority problems. J. Soc. Issues 2 (4), 34–46.
Lövbrand, E., 2009. Revisiting the politics of expertise in light of the Kyoto negotiations on land use change and forestry. Forest Policy Econ. 11, 404–412.
Lund, H.D., Boon, T.E., Nathan, I., 2009. Accountability of experts in the Danish national park process. Forest Policy Econ. 11, 437–445.
Maasen, S., Weingart, P., 2005. What´s new in scientific advice to politics? In: Maasen, S., Weingart, P. (Eds.), Democratization of Expertise? Exploring Novel Forms of Scientific Advice in Political Decision Making – Sociology of the Sciences 24. Springer, Dodrecht, pp. 1–19.
Miller, T.R., Wiek, A., Sarewitz, D., Robinson, J., Olsson, L., Kriebel, D., Loorbach, D., 2014. The future of sustainability science: a solutions-oriented research agenda. Sustain. Sci. 9 (2), 239–246.
Mobjörk, M., 2010. Consulting versus participating transdisciplinarity: a refined classification of transdisciplinary research. Futures 42, 866–873.
Moll, P., Zander, U., 2013. Implementation-oriented and transformative research—Lessons from a project on conservation and sustainable use of forest resources in Ethiopia. Environ. Sci. Policy 28, 82–91.
Morisse-Schilbach, M., Werland, S., 2009. Forstwissenschaften und die Globale Governance des Waldes. Waldökologie, Landschaftsforschung und Naturschutz 8, 107–117.
Nowotny, H., 1999. The place of people in our knowledge. Eur. Rev. 7 (2), 247–262.
Nowotny, H., Scott, P., Gibbons, M., 2001. Re-Thinking Science: Knowledge and the Public in an Age of Uncertainty. Polity Press, Cambridge.
Ojha, H.R., Cameron, J., Kumar, C., 2009. Deliberation or symbolic violence? The governance of community forestry in Nepal. Forest Policy Econ. 11, 365–374.
Pielke Jr., R.A., 2007. The Honest Broker: Making Sense of Science in Policiy and Politics. Cambridge University Press, Cambridge.
Pohl, C., Rist, S., Zimmermann, A., Fry, P., Gurung, G.S., Schneider, F., Speranza Chinwe, I., Kiteme, B., Boillat, S., Serrano, E., Hirsch Hadorn, G., Wiesmann, U., 2010. Researchers' roles in knowledge co-production: experience from sustainability research in Kenya, Switzerland, Bolivia and Nepal. Sci. Public Policy 37 (4), 267–281.
Polk, M., 2014. Achieving the promise of transdisciplinarity: a critical exploration of the relationship between transdisciplinary research and societal problem solving. Sustain. Sci. 9 (4), 439–451.
Polk, M., 2015. Transdisciplinary co-production: Designing and testing a transdisciplinary research framework for societal problem solving. Futures 65, 110–122.
Posner, S.M., McKenzie, E., Ricketts, T.H., 2016. Policy impacts of ecosystem services knowledge. Proceedings of the National Academy of Sciences 113 (7), 1760–1765.
Pregernig, M., 2000. Putting science into practice: the diffusion of scientific knowledge exemplified by the Austrian 'Research Initiative Against Forest Decline'. Forest Policy and Economics 1 (2), 165–176.
Pregernig, M., 2014. Framings of science-policy interactions and their discursive and institutional effects: examples from conservation and environmental policy. Biodivers. Conserv. 23 (14), 3615–3639.
Reed, M., Meagher, L., 2019. Using evidence in environmental and sustainability issues. In: Boaz, A., Davies, H., Fraser, A., Nutley, S. (Eds.), What works now? Evidence

Informed Policy and Practice. Policy Press, Bristol.
Reed, M.S., Graves, A., Dandy, N., Posthumus, H., Hubacek, K., Morris, J., Prell, C., Quinn, C.H., Stringer, L.C., 2009. Who's in and why? A typology of stakeholder analysis methods for natural resource management. J. Environ. Manag. 90 (5), 1933–1949.
Salomaa, A., Paloniemi, R., Hujala, T., Rantala, S., Arponen, A., Niemelä, J., 2016. The use of knowledge in evidence-informed voluntary conservation of Finnish forests. Forest Policy Econ. 73, 90–98.
Sanderson, I., 2002. Evaluation, policy learning and evidence-based policy making. Public Adm. 80 (1), 1–22.
Scholz, R.W., Mieg, H.A., Oswald, J.E., 2000. Transdisciplinarity in groundwater management—towards mutual learning of science and society. Water Air Soil Pollut. 123 (1-4), 477–487.
Scholz, R.W., Lang, D.J., Wiek, A., Walter, A., Stauffacher, M., 2006. Transdisciplinary case studies as a means of sustainability learning. Historial framework and theory. Int. J. Sustain. High. Educ. 7 (3), 226–251.
Stauffacher, M., Flüeler, T., Krütli, P., Scholz, R.W., 2008. Analytic and dynamic approach to collaboration: a transdisciplinary case study on sustainable landscape development in a swiss prealpine region. Syst. Pract. Action Res. 21 (6), 409–422.
Steffek, J., 2009. Discursive legitimation in environmental governance. Forest Policy Econ. 11, 313–318.
Suda, M., Helmle, S., Zormaier, F., 2003. Partizipative Forschung als Schlüssel zur Politikberatung. In: Weber, N. (Ed.), Facetten der Forstpolitikwissenschaft. Dr. Kessler Verlag, pp. 51–58.
Van Kerkhoff, L., Lebel, L., 2006. Linking knowledge and action for sustainable development. Annu. Rev. Environ. Resour. 31, 445–477.
Wagner, K., 2007. Fundierte wissenschaftliche Politikberatung mit Scheuklappen? — analyse einer "Klientelbeziehung" zwischen einer Forstverwaltung und einem Lehrstuhl für Forstpolitik. In: Krott, M., Suda, M. (Eds.), Macht Wissenschaft Politik? VS Verlag für Sozialwissenschaften, Wiesbaden.
Weinberg, A.M., 1972. Science and trans-science. Minerva 10 (3), 484–486.
Winkel, G., Blondet, M., Borrass, L., Frei, T., Geitzenauer, M., Gruppe, A., Jump, A., de Koning, J., Sotirov, M., Weiss, G., Winter, S., Turnhout, E., 2015. The implementation of Natura 2000 in forests: a trans- and interdisciplinary assessment of challenges and choices. Environ. Sci. Policy 52, 23–32.
Zscheischler, J., Rogga, S., 2015. Transdisciplinarity in land use science – a review of concepts, empirical findings and current practices. Futures 65, 28–44.

Overview of articles included in this cumulative Ph.D. thesis

(in accordance with the guideline for cumulative dissertations in Sustainability Science [January 2012], in the following termed "the guideline")

Title of Ph.D. thesis: Assessing transdisciplinary research in sustainability science

Papers included:

Article 1 [A1]: **Jahn, Stephanie**, Jens Newig, Daniel J. Lang, Judith Kahle, and Matthias Bergmann. 2022. Demarcating transdisciplinary research in sustainability science – Five clusters of research modes based on evidence from 59 research projects. *Sustainable Development*, 30(2), 343-357.

Article 2 [A2]: Newig, Jens, **Stephanie Jahn**, Daniel J. Lang, Judith Kahle, and Matthias Bergmann. 2019. Linking modes of research to their scientific and societal outcomes. Evidence from 81 sustainability-oriented research projects. *Environmental Science and Policy* 101, 147-155.

Article 3 [A3]: Juerges, Nataly and **Stephanie Jahn**. 2020. German forest management stakeholders at the science-society interface: Their views on problem definition, knowledge production and research utilization. *Forest Policy and Economics* 111, 102076.

Authors' contributions to the articles and articles publication status (according to §16 of the guideline):

Article #	Short Title	Specific contributions of all authors	Author status	Weighting factor	Publication status	Conference Contributions
1	Demarcating transdisciplinary research in sustainability science	Development of conceptual and methodological approach: JN, DJL, SJ, JK, MBM Data collection and preparation: SJ Execution of research: SJ Analysis/interpretation of data: SJ, JN Structure, argumentation: SJ, JN	Co-author with predominant contribution	1,0	Published in *Sustainable Development* (JIF: 8.562, Five Year: 7.403)	Tagung Naturkundemuseum, TD Academy Workshop, IASS Tuesday Talk, ITD 2021

Article #	Short Title	Specific contributions of all authors	Author status	Weighting factor	Publication status	Conference Contributions
		Writing or substantive rewriting of the manuscript: SJ, JN, DJL Commenting and revision of the manuscript: MBM				
2	Linking modes of research to their scientific and societal outcomes	Development of conceptual and methodological approach: JN, DJL, SJ, JK, MBM Data collection and preparation: SJ, JK Execution of research: SJ, JK Analysis/interpretation of data: JN, SJ, JK, DJL Structure, argumentation: JN, SJ, DJL, JK Writing or substantive rewriting of the manuscript: JN, SJ, JK, DJL Commenting and revision of the manuscript: MBM	Co-author with equal contribution	1,0	Published in *Environmental Science and Policy* (JIF: 6.424, Five Year: 7.027)	ITD 2019
3	German forest management stakeholders at the science-society interface	Development of conceptual and methodological approach: NJ, SJ Narrative literature review: SJ Data collection and preparation: NJ Execution of research: NJ Analysis/interpretation of data: NJ, SJ Structure, argumentation: NJ, SJ Writing or substantive rewriting of the manuscript: SJ, NJ	Co-author with equal contribution	1,0	Published in *Forest Policy and Economics* (JIF: 4.259, Five Year: 3.954)	
				3,0		

Explanations

Specific contributions of all authors

DJL: Daniel J. Lang, JK: Judith Kahle, JN: Jens Newig, MBM: Matthias Bergmann, NJ: Nataly Juerges, SJ: Stephanie Jahn

Author status

according to §12b of the guideline:
Single author [Allein-Autorenschaft] = Own contribution amounts to 100%.
Co-author with predominant contribution [Überwiegender Anteil] = Own contribution is greater than the individual share of all other co-authors and is at least 35%.
Co-author with equal contribution [Gleicher Anteil] = (1) own contribution is as high as the share of other co-authors, (2) no other co-author has a contribution higher than the own contribution, and (3) the own contribution is at least 25%.
Co-author with important contribution [Wichtiger Anteil] = own contribution is at least 25%, but is insufficient to qualify as single authorship, predominant or equal contribution.
Co-author with small contribution [Geringer Anteil] = own contribution is less than 20%.

Weighting factor

according to §14 of the guideline:
Single author [Allein-Autorenschaft] 1.0
Co-author with predominant contribution [Überwiegender Anteil] 1.0
Co-author with equal contribution [Gleicher Anteil] 1.0
Co-author with important contribution [Wichtiger Anteil] 0.5
Co-author with small contribution [Geringer Anteil] 0

Publication status

Clarivate Web of Science Journal Impact Factor (JIF) and Five Year Journal Impact Factor 2021

Conference contributions (acronym, society, date, venue, website)

Tagung Naturkundemuseum, Wissenschaftsjahr „Nachgefragt“, Museum für Naturkunde Berlin, 26.09.2022, Berlin, https://www.museumfuernaturkunde.berlin/de/wissenschaft/chancen-und-grenzen-der-partizipation-der-wissenschaft

td Academy Workshop, tdAcademy, 10.06.2022, online, https://td-academy.org/en/events-archiv/was-hat-die-wissenschaft-davon-reflexionen-ueber-die-wissenschaftlichen-wirkungen-transdisziplinaerer-forschung/

IASS Tuesday Talk, Institute for Advanced Sustainability Studies – IASS, 19.04.2022, online, https://www.rifs-potsdam.de/de/veranstaltungen/iass-tuesday-talks

ITD 2021, Swiss Academy of Arts and Sciences, Network for transdisciplinary research (td-net), 13. – 17.09.2021, online https://transdisciplinarity.ch/de/veranstaltungen/itd-conferences/itd-conference-2021/

ITD 2019, Swiss Academy of Arts and Sciences, Network for transdisciplinary research (td-net), 11. – 13.09.2019, Gothenburg (SEW) https://scnat.ch/de/uuid/i/36a720a8-ccc8-5ac1-911a-bff6f29e42ca-International_Transdisciplinarity_Conference_2019

Declaration (according to §16 of the guideline)

I avouch that all information given in this appendix is true in each instance and overall.