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Originally published in:
Current Research in Environmental Sustainability 4, https://doi.org/10.1016/j.crsust.2022.100180

Current Research in Environmental Sustainability 4 (2022) 100180

Contents lists available at ScienceDirect

Current Research in Environmental Sustainability

journal homepage: www.sciencedirect.com/journal/current-research-in-environmental-sustainability

What are the effects of transdisciplinary research projects in the global North and South? A comparative analysis

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ARTICLE INFO

Keywords:
Transdisciplinary research
Sustainable development
Project effects
North-South research partnerships
Evaluation

ABSTRACT

Transdisciplinary research (TD) integrates knowledge from different scientific disciplines, as well as from research and practice. Research and practice therefore describe TD as well-suited for addressing complex sustainability challenges. However, the effects of TD on sustainable development are difficult to assess, as such projects produce manifold, interconnected effects through nonlinear processes, contingent on different contexts. In this article, we use a systematic literature review of 101 TD projects to assess the different effects of TD projects and their interconnections. We distinguish between North-South TD projects and TD projects within the global North. Due to differences in terms of historical development and context, we expect to observe differences in the effects they achieve. We find that North-South projects scored higher for societal effects and uptake of knowledge, while projects in the global North produced more tangible outputs, such as academic publications. In terms of interconnections of effects, N-S projects emphasize inclusion more strongly than global North projects, due to an increased awareness of differences between different project participants. However, effects related to uptake of knowledge, learning, and societal effects are often interconnected in both types of projects. This article improves our understanding of the prominence of different effects of TD projects, the interconnections between effects they produce, and the differences between N-S and North projects. Acknowledging this diversity of effects is important, not least for evaluating the efficacy of TD projects.

1. Introduction

Society faces a range of highly complex and multifaceted sustainability challenges such as biodiversity loss, nutrient loss in soils, or environmental pollution. In this context, both researchers and practitioners are increasingly questioning the capacity of "traditional" scientific research, that is, research with a purely disciplinary focus, to provide the evidence needed for supporting the transformations to address major sustainability challenges (Colglazier, 2015; Lang et al., 2012; Sachs et al., 2019; Fritz and Binder, 2018). By contrast, both the integration of disciplinary knowledge from different fields such as agronomy and engineering and input from practitioners, such as from farmers or utilities and fertilizer companies (Lang et al., 2012; Belcher et al., 2016) is crucial to support transformations such as shifting from synthetic fertilizer use to the use of recycled nutrients to optimize soil fertility (as an example). Transdisciplinary (TD) research tackles these dimensions by integrating knowledge from different scientific disciplines, on the one hand, and from research and practice, on the other hand (Lang et al., 2012; Belcher et al., 2016). As such, TD has the potential to produce holistic and applicable system, target, and transformation knowledge and thus to support the transformation toward sustainable development (Schneider et al., 2019a).

The existing literature contains only scarce empirical evidence on the contribution of TD projects to addressing sustainability challenges. We observe three major research gaps. First, TD projects produce diverse effects ranging from knowledge production, to pure academic outputs, to the creation of trust between the participants involved. Various scholars have developed frameworks, schemes, and evaluation approaches to describe this diversity of effects. Authors such as Jahn, et al. (Jahn et al., 2021) and Tribaldos, et al. (Tribaldos et al., 2020) provide important insights into different styles of TD collaborations and conditions (such as the sustainability problem a project is addressing or the institutional background of projects) that influence the effects. However, evidence on what effects are most prominent in TD projects is scarce

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https://doi.org/10.1016/j.crsust.2022.100180
Received 1 August 2021; Received in revised form 21 July 2022; Accepted 28 July 2022
Available online 11 August 2022

(Schneider et al., 2019a; Muhonen et al., 2019; Fritz et al., 2019). Second, research shows that the pathways for achieving effects through TD projects are multifold and rarely linear (Schneider et al., 2019a; Muhonen et al., 2019; Fritz et al., 2019). Nevertheless, the relations between the different effects or their commonalities have not been sufficiently studied. Only Chambers, et al. (Chambers et al., 2021) have specifically analyzed trade-offs and synergies between different effects. Still, they do not consider differences between different research contexts.

Third, TD projects have different traditions, and are highly contingent on their contexts. One important contextual difference is notable between TD projects conducted in a North-South (N-S) research partnership and projects conducted in the global North (North projects). The N-S research field has traditionally placed a strong emphasis on the participation of local stakeholders and the practical applicability of results (Saric et al., 2019; Hirsch Hadorn et al., 2006; Brutschin and Wiesmann, 2008; Bradley, 2008). In contrast, North research projects have focused on creating knowledge, without taking a participatory approach, at least until recently (Scholz and Marks, 2001; Scholz and Steiner, 2015; Mobjörk, 2010). Beyond these different foci, N-S and North projects also take place in very different contexts (with the N-S projects typically being implemented in the South), which arguably influences their effects.

Given the lack of knowledge on effects of TD projects in different contexts, we pose the following research question: *How do effects of N-S TD projects differ from the effects of TD projects in the global North?* By answering this question, we contribute to the literature by assessing the prominence of different effects of TD projects as well as the interconnections of these effects in different contexts. Based on a literature review and evidence from 101 TD projects, the article presents which effects are how prominent in TD projects, and how the effects are interconnected, and create potential synergies and trade-offs between them (Schneider et al., 2019a; Muhonen et al., 2019; Fritz et al., 2019). Both pieces of information are crucial to an appropriate evaluation of TD projects (Belcher et al., 2016). Furthermore, the article presents important differences and similarities between the effects of N-S projects and TD projects within the global North. For better comparability of the cases and a thematic focus of this article, we limit ourself in this review on TD research in sustainable development.

In the next section, we delineate different categories of effects and their interconnections and outline the different research traditions in both North and North-South contexts. We then outline our methods, grounded in a literature review, descriptive statistics and a clustering approach, before finally presenting our results.

2. Conceptual background

To contextualize the core research gaps we address in this article, we provide a comprehensive overview on 1) the different types of effects and their interconnections and 2) TD projects in the global North vs. within North-South research.

2.1. Types of effects and interconnections between effects

From a traditional academic point of view, effects of projects are typically defined as tangible outputs such as academic publications or fulfilled project goals. In order to capture the effects of TD projects, several authors call for a broader perspective on the different potential effects (Lux et al., 2019; Jacobi et al., 2020; Schneider and Buser, 2018). We thus follow Fritz, et al. (Fritz et al., 2019) who propose the general term “effect” to encompass the wide diversity of results of TD projects, ranging from increased motivation to uptake of produced knowledge to network effects. A variety of schemes and frameworks describe the effects of TD projects at different levels of abstraction. They range from rather broad categories of societal and academic outputs and impacts (Newig et al., 2019) to overarching impact categories such as learning, and real-world transformations (Tribaldos et al., 2020; Chambers et al., 2021). Other authors include effects such as the creation of networks or increased decision-making capacity (Fritz et al., 2019; Wiek et al., 2014; Luederitz et al., 2017).

One category which is present in the literature is *knowledge production*. Lang, et al. (Lang et al., 2012) argue that beyond fulfilling project goals, an evaluation should also consider different types of *knowledge production* in terms of acquiring system, target, or transformation knowledge (Belcher et al., 2016; Belcher et al., 2019). System knowledge includes knowledge used to describe a given system or problem (Pohl and Hadorn, 2007). By integrating disciplines and knowledge of non-academic stakeholders, TD research can lead to holistic system knowledge. Target knowledge is defined as knowledge of the preferred future or outcome of a certain process (Schneider and Rist, 2014). TD can increase the applicability of results from, for example, scenario analysis by including the perspective of concerned stakeholders, which creates target knowledge (Walz et al., 2007). Furthermore, using TD approaches to generate target knowledge helps to identify stakeholders’ underlying values and motivations (Karrasch et al., 2022). Finally, transformation knowledge describes the knowledge, measures, or tools to reach the targets (Pohl and Hadorn, 2007). Achieving these different types of knowledge can be summarized as *knowledge production*. TD research can also foster *uptake of knowledge*. This includes the uptake in practice but also in policy and research. Due to the involvement of stakeholders and different disciplines, TD projects generate knowledge applicable for practice that is then potentially taken up by a target group (Schneider et al., 2019a; Schneider and Rist, 2014; Hansson and Polk, 2018). Another category of effects includes traditional, tangible outputs of research processes in the form of publications or reports for academic participants and stakeholders (Mitchell et al., 2015; Koier and Horlings, 2015; Kaufmann and Kasztler, 2009). These can be called *products*, and include, for example, publications or outreach material. Furthermore, studies describe effects related to *learning*, such as capacity building or increases in problem awareness (Tribaldos et al., 2020; Muhonen et al., 2019; Fritz et al., 2019). Lastly, scholars argue that TD projects also generate impact through societal factors, such as by fostering networks or increased trust (Chambers et al., 2021; Wiek et al., 2014; Schneider et al., 2019b). We describe these as *societal effects*.

As TD projects involve multifold and rarely linear pathways for achieving effects, interactions between different effects are crucial (Schneider et al., 2019a; Muhonen et al., 2019; Fritz et al., 2019). Newly produced knowledge might, for example, first increase the problem awareness of project participants, and then eventually lead to changes in behavior. At the same time, research shows that projects which focus on certain effects of TD projects might struggle to achieve other effects (Schneider et al., 2019a; Chambers et al., 2021). Chambers et al. find several trade-offs between different effects of TD projects. One example is that they find that TD projects which were successfully producing scientific knowledge often failed in achieving other effects such as uptake in policy.

2.2. TD projects in the global North and South

TD projects in a N-S context differ from projects in the global North, given different historical developments of research traditions. Disciplinary research in international development has traditionally started with problems perceived by the researchers, and resulted in solutions propagated by them. This dynamic shifted in the 1970s, when experience showed that integrating the perspective of local stakeholders through participation could increase the uptake of project results (Hirsch Hadorn et al., 2006; Brutschin and Wiesmann, 2008). Methodologies such as participatory rural appraisal or participatory action research (PAR) evolved in response to recognizing that traditional, top-down approaches to research for development efforts were largely ineffective (Chambers, 1994; Wadsworth, 1998) and, hence, PAR encourages researchers and extension officers to act as facilitators in an

equal partnership with the local stakeholders (Chambers, 1994). The evolution of N-S research partnerships led to an integration of "northern ideas" of TD, focusing on creating knowledge for society and the "southern ideas" of participation and equal partnerships (Hirsch Hadorn et al., 2006). Research suggests (Brutschin and Wiesmann, 2008; Khan et al., 2013) that TD projects within N-S research partnerships focus on effects that are potentially more relevant and applicable for the stakeholders involved, and tend to take context specificities into account (e.g., focusing on *societal effects* rather than *products*). In contrast, existing literature indicates that projects within the global North might not focus as much on effects applicable for stakeholders and on context conditions (Hirsch Hadorn et al., 2006). Furthermore, due to the additional transnational dimension, N-S research projects offer opportunities for joint learning, capacity building, and exchange for both partners to a degree that might not be possible in projects within the global North (Bradley, 2008; Ott and Kiteme, 2016). Research also shows that N-S research partnerships may come along with power imbalances, as funding and project coordination is managed mostly by organizations in the global North (Tribaldos et al., 2020; Ott and Kiteme, 2016; Blicharska et al., 2017; Zingerli, 2010). Such imbalances and implicit hierarchies complicate both collaboration and effective and efficient implementation of projects (Blicharska et al., 2017). Furthermore, translation issues and differences in research cultures can complicate the research process in N-S partnerships, and potentially influence their effects (Schmidt and Pröpper, 2017; Bréthaut et al., 2019).

3. Methods and data

We answer our research question of *how effects of N-S TD projects differ from TD projects in the global North* by focusing on two dimensions: the prominence of the effects and their interconnections. We analyze both dimensions for N-S projects versus projects within the global North. We rely on a literature review based on cases of TD projects. In the subsequent section, we first present how we identified relevant articles. Second, we elaborate how we coded them according to our coding scheme. Third, we specify how we applied descriptive statistics to the data from the literature review to study the frequency of effects, and how we used a clustering approach to study the interconnections of effects. Finally, we present how we compared the effects between N-S projects and North projects.

3.1. Identification of the literature

Following Bramer, et al. (Bramer et al., 2018), we first identified the key concepts needed to address the research question. These key concepts are TD projects and their effects, as we are aiming to identify links between them. The focus on TD research projects for sustainable development provides a third concept. Second, we use a broad range of search terms related to the three concepts under study: TD research projects, effects, and sustainable development. Table 1 shows the final selection of the search terms. The terms for each concept were combined with the Boolean operator OR while we combined the three concepts with AND operators. A search in the Web of Science and Scopus databases of articles and reviews written in English and published in 2010 or later resulted in a total of 745 publications.[1] For all search terms, we used a title-abstract search. We explicitly excluded searching the keywords, as publications that only mention our search terms in the keywords but not in the abstract or title were often only marginally related to our focus.

Based on our definition of TD research, we included search terms that describe research approaches covering different disciplines and non-academic stakeholders. We checked the robustness of our search approach by asking three experts in the field of TD research to check our list of search terms for completeness. To identify articles dealing with effects of projects, we included a range of related search terms. Alongside terms directly related to effects, we included terms related to evaluation and goal achievement, as well as to the three levels of the logic model—output, outcome, and impact—that is often used in project evaluation (Savaya and Waysman, 2005). We followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses statement (PRISMA) to describe the process of project selection. Fig. 1 shows the process of project selection during the literature review.

Table 1
Final selection of search terms.

TD Research Project	Effects	Topic
Title-Abs (OR)	*Title-Abs (OR)*	*Title-Abs (OR)*
transdisciplinar*	Output	Sustainability
"research-practice integration"	Impact	Sustainable Development
"collaborative research"	Evaluation	
"community-based research"	Assessment	
"community-led research"	Effic*	
"participatory action research"	Effect*	
"community-based action research"	"achiev* of objective"	
"co-production of knowledge"	"achiev* of goal"	
"knowledge co-production"	"goal achiev*"	
"transdisciplinary co-production"	"achiev* of objective"	
"co-producing knowledge"		
"co-creation of knowledge"		
"knowledge co-creation"		
"co-creating knowledge"		
"mode 2 research"		
"mode 2 science"		
"mode-2 research"		
"mode-2 science"		
"postnormal science"		
"post-normal science"		
"transformative research"		
"transformative science"		
"living lab*"		
"Real-world lab*"		

All steps were conducted by the first author of the article in frequent exchange with the coauthors. We first conducted an abstract scan to assess whether the article was relevant, based on the following conditions: 1) The article reports on at least one TD project; 2) The project uses a TD approach according to our definition, i.e. integrates processes across several scientific disciplines and across research and practice (Belcher et al., 2016); 3) The article presents some information about project effects; 4) The project relates to sustainable development. Examples for articles not included in our sample are theory papers with no description of any empirical results from one or several projects, or papers based on general expert opinions but not on the experience from one or several projects (violating condition 1). Furthermore, some articles described collaborative processes with no researcher involvement (violating condition 2). We also excluded articles in which the authors applied TD research, but the publication presented the results of the TD project rather than reflecting on the effects of the TD approach (violating condition 3). Following Newig, et al. (Newig et al., 2019) we excluded articles that used the term "sustainability" only to describe long-term effects (e.g., long-term effects of a medical treatment) (violating condition 4).

The abstract scan according to these four conditions led us to exclude 564 articles, resulting in a set of 181 articles. We then used the same four conditions again for a full-text scan, leading to a final selection of 66 articles. Fifteen articles include and discuss several cases of TD research projects. We split these articles into single cases. Studies including multiple cases but providing overall and synthesized results are

[1] The final search was conducted on March 4th 2020

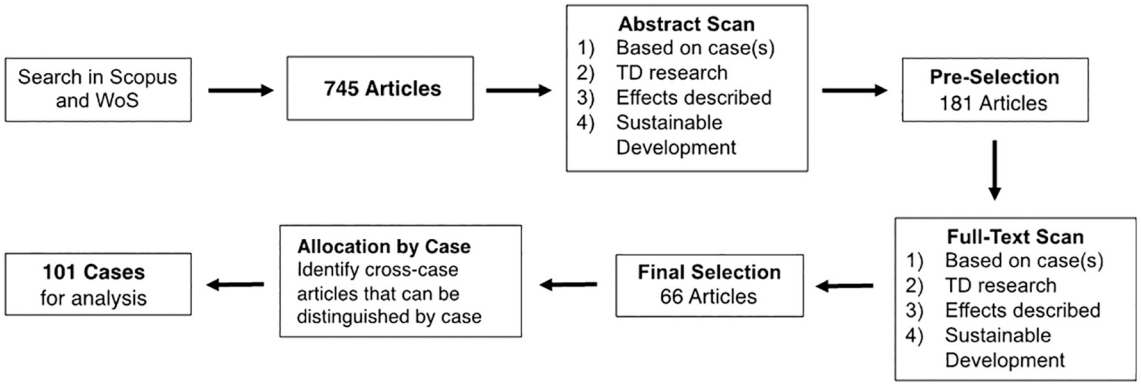

Fig. 1. Overview of the process of the systematic literature review based on the PRISMA statement.

considered as one case. This resulted in a final set of 101 cases: 50 N-S projects and 51 North projects[2]. The cases show a high variety of topics, ranging from agriculture or natural resources to sanitation or energy. We present a numbered list of cases in the appendix. There is a minimal overlap of two papers included in our set of cases with the literature used in the "conceptual background" section to deduce the different categories of effects.

4. Coding of the literature

As introduced previously (see Conceptual Background), existing approaches for categorizing the effects of TD projects (e.g. (Jahn et al., 2021; Tribaldos et al., 2020)) have different abstraction levels. For this study, we use a mix of different approaches by summarizing specific effects within broader categories of effects. In the extant literature we identify five categories of effects that TD projects may produce: *knowledge production, uptake of knowledge, products, learning and societal effects*, summarized in Table 2. The table presents the effects belonging to each category, and refers to the respective literature (or the indication that it is an inductively defined effect, respectively). An example of a text segment for each effect can be found in the appendix.

We used the software MaxQDA for coding the projects. The coding procedure was as follows: for each case, we first collected descriptive data on the thematic area of the study, regarding whether case was part of a single project study or of a cross-project comparison, and whether the case was a N-S or a North case. We then specifically searched for text segments that provide information on project effects and chose one or several codes to specify the observed effects. We only considered text segments from the results and the discussion parts of the papers to ensure that the coded segments were in fact based on observations and data, and not just on assumptions that are often formulated in conclusions. During the coding process, we also found text segments fitting our definition of an effect of a TD project but not fitting one of our effects that we had already developed deductively (Robson, 2002). Such segments were inductively coded under additional effects (Robson, 2002). In the end, we derived one additional effect - "inclusion" - during the coding procedure. For each project, we thus had a binary coding of whether any of the 17 effects were present or not. While only the first author did the actual coding, the second and third author were involved in the pretesting and continuous discussions of questions during the coding procedure. We conducted a pretest with a selection of 10 publications to iteratively compare the coding results and adapt the coding system accordingly.

[2] To distinguish between North and N-S projects, we considered the location of the affiliation of the involved researchers and practitioners and not their nationality. We distinguished between the "global South" and "global North" based on the classification from the United Nations (Finance Center for South-South Cooperation, 2015).

5. Descriptive statistics and cluster analysis

For the analysis of the data from the literature review, we first used descriptive statistics to analyze the prominence of the effects. More specifically, we ascertained which effects were observed in what share of the studied cases. Second, we analyzed how different effects are interconnected with each other. More specifically, we studied which effects often appear together, and thus potentially influence each other. Therefore, we relied on a partitioning around medoids (PAM) clustering approach to group the effects into clusters, beyond dyadic relations between effects (Schubert and Rousseeuw, 2019). As a distance measure, we relied on the Jaccard similarity index. The Jaccard similarity index indicates the share of cases where any two effects co-occurred, as compared to the share of cases where only one of both effects was described (Choi et al., 2010). The PAM clustering algorithm groups the different elements around medoids, which are the elements that have the smallest dissimilarity to all other elements in the cluster (Schubert and Rousseeuw, 2019). The results of the clustering thus show which effects group together based on their appearance in the studied cases. Effects that are grouped in the same cluster thus have minimal dissimilarities. The PAM clustering is a hard clustering algorithm, compared to fuzzy clustering approaches, where one element can belong to different clusters; hard clustering, in contrast, sorts each element in one distinct cluster (Miyamoto and Umayahara, 2000). We used the average silhouette method to determine the optimal number of clusters (Kaufman and Rousseeuw, 2009) and found that for both the N-S and the North cases, six clusters was optimal (see Appendix). All of these measures were applied to the set of N-S cases ($N = 50$) and North cases ($N = 51$), allowing for a comparison between them.

6. Analysis

6.1. Effects and their prominence

Fig. 2 presents how prominently the five different categories of effects were present in TD projects. More specifically, Fig. 2 shows the share of projects (between 0 and 1, representing 0% and 100%, respectively) for which the individual effects within the five categories were reported. Additionally, Fig. 2 distinguishes the share of N-S cases (upper part, in green) and North cases (lower part, in blue). The black horizontal lines indicate the average share for each category of effects.

6.2. Knowledge production

We find that for both N-S and North projects, high shares of TD projects report effects of *knowledge production*. For the North projects, *knowledge production* is the category with the highest average share,

Table 2
Overview coding of effects.

Category	Effect (Abbreviation)	Description	Deductive (Literature) vs. Inductive (In situ)
Knowledge Production	**System knowledge** (K_System)	System knowledge includes knowledge used to describe a given system or problem by integrating disciplines and the knowledge of nonacademic stakeholders.	(Pohl and Hadorn, 2007)
	Target Knowledge (K_Target)	Target knowledge is defined as knowledge of the preferred future or outcome of a certain process. This includes, for example, scenario analysis or the development of specific target values (e.g., scenario analysis).	(Schneider and Rist, 2014; Walz et al., 2007)
	Transformation Knowledge (K_Transform)	Transformation knowledge describes the measures or tools that can be used to reach the targets and is thus fundamental when it comes to fostering societal transformation toward sustainable development (e.g., management practices, planning tools, technologies).	(Luederitz et al., 2017; Pohl and Hadorn, 2007)
Uptake of Knowledge	**Uptake in Practice** (Uptake_Pr)	The uptake of knowledge or technologies by the involved stakeholders. This can include applying a technology or using the produced knowledge to change processes.	(Fritz et al., 2019; Wiek et al., 2014; Luederitz et al., 2017; Polk, 2014)
	Uptake in Policy (Uptake_Po)	Uptake in policy is considered a key aspect of TD projects. We considered observations on the uptake of results into political dialogue and its impact on the development of new policies.	(Fritz et al., 2019; Wiek et al., 2014; Luederitz et al., 2017; Polk, 2014)
	Uptake in Science (Uptake_S)	This effect describes the re-uptake of insights in science gained through research projects. This includes results in the form of data and produced knowledge but also new methods or strategies in conducting research.	(Fritz et al., 2019; Wiek et al., 2014)
	Change in Practices (Change)	Change in practices includes direct behavior change induced through the research (e.g., changing the harvesting schedule).	(Fritz et al., 2019; Wiek et al., 2014)
	Durability (Durability)	The effect of durability describes whether the project includes long-term uptake or changes. This includes follow-up projects but also when other institutions take over the projects.	(Douthwaite et al., 2017; Wyborn et al., 2019)
	Transfer of Results (Transfer)	The effect of transfer includes the transfer of learning from the project to another geographical or thematic focus.	(Fritz et al., 2019; Luederitz et al., 2017)
Products	**Academic Outputs** (O_Academic)	Academic outputs include publications, presentations at conferences, or other ways of spreading produced knowledge through academic channels.	(Mitchell et al., 2015; Koier and Horlings, 2015; Kaufmann and Kasztler, 2009)
	Outreach Outputs (O_Outreach)	Outreach outputs include any form of outreach conducted during the project (brochures, movies exhibitons, etc.).	(Mitchell et al., 2015; Koier and Horlings, 2015; Kaufmann and Kasztler, 2009)
Learning	**Problem Awareness** (Prob_Awar)	Problem awareness includes the increased awareness of a certain problem and the need to act. It can also include becoming aware of another perspective regarding a certain problem.	(Tribaldos et al., 2020; Fritz et al., 2019; Chambers et al., 2021; Wiek et al., 2014)
	Capacity Building (Capacity_A; Capacity_S)	Capacity building includes the increase in technical skills and competencies as well as intra- and interpersonal skills and competencies. We considered the capacity building of stakeholders (Capacity_S) as well as of the academic participants (Capacity_A).	(Tribaldos et al., 2020; Fritz et al., 2019; Chambers et al., 2021; Wiek et al., 2014; Luederitz et al., 2017)
Societal Effects	**Building Trust** (Trust)	Building trust describes the perceived increase in trust between different project participants but also trust in research results.	(Lux et al., 2019; Jacobi et al., 2020; Schneider and Buser, 2018; Wiek et al., 2014)
	Networks and Relationships (Network)	This effect includes the forming of new relationships and the forming and strengthening of networks throughout the project.	(Fritz et al., 2019; Schneider and Buser, 2018)
	Inclusion (Inclusion)	This effect includes whether the different project participants felt included in the research process and whether they felt the project was relevant to them.	Inductive

while for the N-S projects it is the second most prominent category, together with *learning*. The average share of *knowledge production* is higher for cases in the global North due to a much higher share of studies that reported on transformation knowledge. For North cases we find transformation knowledge in more than 60% of the cases, while less than 40% of N-S cases report this effect. For system and target knowledge we do not observe major differences between N-S and North projects.

6.3. Uptake of knowledge

On average, N-S cases scored slightly higher in the *uptake of knowledge* category (25% vs. 22%). Among the individual effects within that category, uptake in practice is more than twice as prominent in N-S cases (~50%) than in North cases (~20%). The same pattern, with slightly smaller differences though, can be observed for the effect of uptake in policy. One assumption about why the level of knowledge uptake in practice and policy is higher for N-S projects could be due to the development of TD research in N-S projects. With the development of approaches such as participatory action research North-South research projects started to place a strong focus on driving change and the needs of the stakeholders (Brutschin and Wiesmann, 2008; Khan et al., 2013). Thus, we assume that the research questions tackled in N-S TD projects tend to be more specific, context-senstive, and concrete, which in turn facilitates direct uptake.

Cases within the global North scored around twice as high for the effects of uptake in science (29% vs. 14% in N-S cases) and transfer (21% vs. 12% in N-S cases). The higher uptake in science and the higher level of transfer could potentially be due to researchers from the global North being cited more prominently (Haelewaters et al., 2021; Liverpool, 2021; Amarante et al., 2021). In general, as compared to non-TD projects, generalizability of results of TD projects is more difficult due to their often very context-specific design (Polk, 2014; Wanner et al., 2018). The focus on the participation and inclusion of local stakeholders of TD projects (as shown in Fig. 2) might lead to a lower generalizability of results and thus less uptake in science and less transfer. The last two effects of the category *uptake of knowledge* —change and durability—showed no important differences between N-S cases and North cases. Both effects scored below average in the uptake of knowledge category.

6.4. Products

Projects in the global North also produce more effects in the *products* category. This category contains outputs for outreach, such as reports or brochures, as well as academic outputs. Outreach outputs are produced

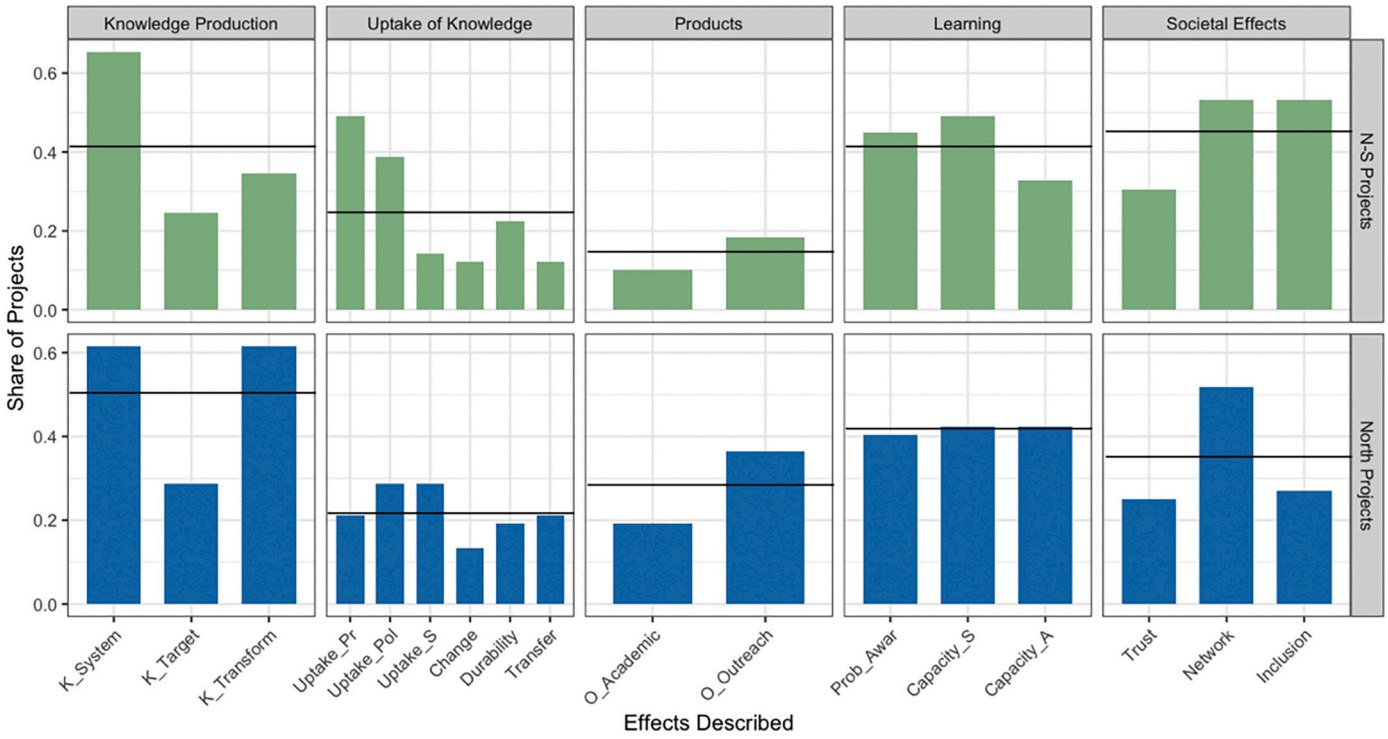

Fig. 2. Overview of effects described in N-S and North cases grouped by effect category.

more prominently than academic outputs in both N-S TD projects as well as North TD projects. We thus observe that independent of the type of TD project, academic outputs are less present than outreach outputs. In one of the North cases (Case 23; see appendix 1) the authors specifically find that the academic performance of TD projects is lower than in projects without non-academic participants. Jahn, et al. (Jahn et al., 2021) describe a trade-off between production of scientific knowledge in the form of papers (i.e., academic outputs) and inclusion of stakeholders (allowing for outreach outputs).

6.5. Learning

All three effects within the *learning* category are similarily prominent. Still, we observed some differences between the N-S and the North projects. While N-S cases scored slightly higher for problem awareness and the capacity building of stakeholders, the largest difference lies in the share of studies reporting capacity building for academic partners that scored around 10% higher for North projects. Overall, we can state that for both N-S and North projects, capacity building is a relevant effect for both stakeholders and academic partners. Furthermore, we observe from our cases that capacity building does not only include concrete methods or technical skills but especially also the acquisition of soft skills. This acquisition of soft skills is illustrated by the following example from Schäpke, et al. (Schäpke et al., 2017) (Case 13–14; see Appendix 1):

> *"speaking one's own mind in public, better communication, creativity, organisation, leadership, an increase in self-reflexivity and the feeling of responsibility as well as the ability to work in a team and the understanding for political work." (p. 16).*

6.6. Societal effects

The N-S cases have a higher average than the North cases for the category of *societal effects*. While the difference is negligible for the effect of relationships, it is largest for the effect inclusion (53% vs. 27 in North cases). We interpret that researchers who are working in N-S research projects with participants from different countries and with different cultural and societal backgrounds, could have an increased awareness for differences and potential conflicts. This awareness could then, in turn, have a positive effect on inclusion (Bradley, 2008; Ott and Kiteme, 2016).

6.7. Interconnections of effects

Besides the prominence of the different effects within the five effect cateogires, we studied how the different effects are interconnected by examining their coappearance in the same projects. We separately applied this method to both the set of North projects ($N = 51$) and N-S projects ($N = 50$). Fig. 3 shows the first two dimensions of a cluster plot with six clusters for the N-S projects. The clusters are numbered and colored accordingly. We see overlaps between some of the clusters for the N-S projects. This indicates that the identification of clear clusters is difficult because there are no large differences in the dissimilarities between certain effects.

The first cluster (1) does not overlap with any other clusters, and thus demonstrates a separate set of effects. It consists of the three effects of the *knowledge production* category (system, target, and transformation knowledge) and the effects of inclusion and academic capacity building. The relation between the effects from the *knowledge production* category and inclusion indicates that within N-S projects, stakeholders might be strongly included in the production of different effects of *knowledge production*. This is in line with existing literature on the evolvement of TD research in N-S projects (Hirsch Hadorn et al., 2006; Brutschin and Wiesmann, 2008). Approaches such as participatory action research have a strong focus on change and aim to put the stakeholders and their needs in the center (Khan et al., 2013). Furthermore, we assume that TD projects emphasizing inclusion might provide an opportunity to academic participants for capacity building. Furthermore, academic capacity building is connected to *knowledge production* as N-S projects often involve students in the research project as a way of building local research capacity. This is illustrated by an example reported by A

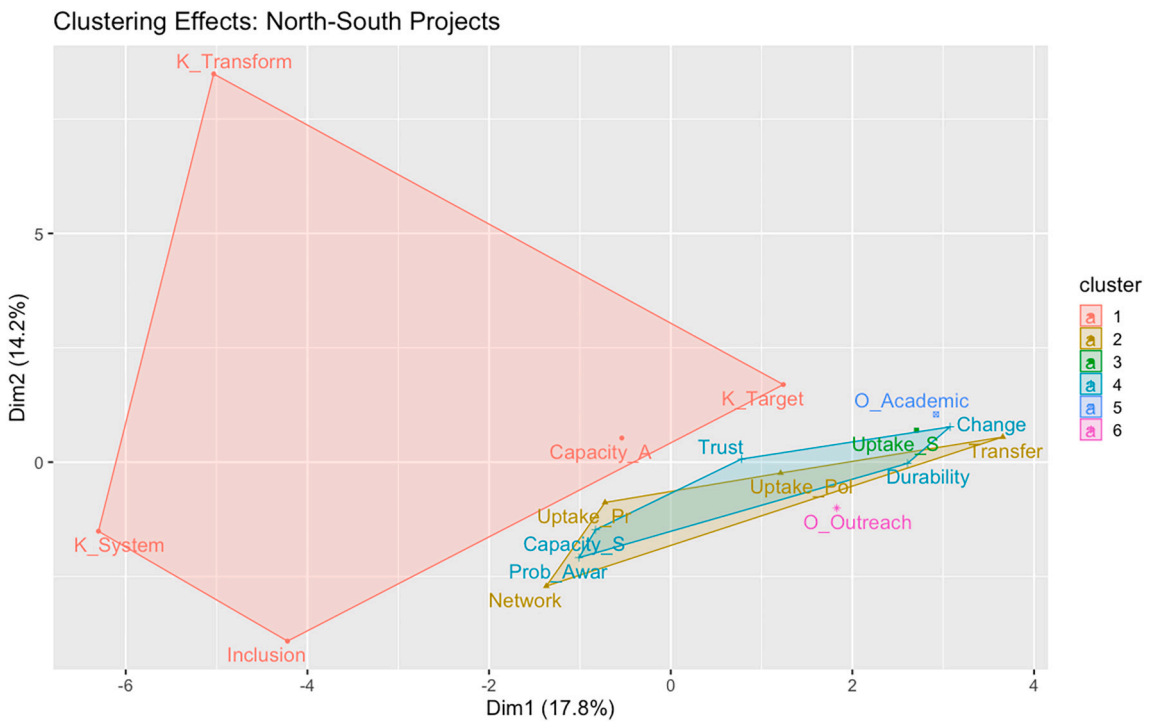

Fig. 3. Cluster results of the effects of N-S projects.

Ambole, et al. (Ambole et al., 2019) (Case 101; see Appendix 1):

> *"Another significant outcome of the project is the participation of graduate students from the respective host universities as field research assistants in the project studies. In Kenya, one graduate student successfully defended her thesis that was based entirely on the field work in Mathare. By working with students, the researchers fulfilled one of their research objectives of building local capacity for doing transdisciplinary research." (p. 215).*

Cluster (2) consists of the effects uptake of knowledge in practice and policy, transfer, and networks. The finding that these four effects cluster together is in line with other studies which emphasize the role of networks and relationships for the uptake of knowledge (Henry and Dietz, 2011; Pärli et al., 2021; Crona and Parker, 2011).

Cluster (4) consists of the problem awareness effects, the capacity building of stakeholders, changes in behavior, the durability of the projects, and trust. This cluster is interesting as it consists of effects from the *uptake of knowledge, learning,* and *societal effects* categories. A possible explanation for this mix of effects in the same cluster is that capacity building and trust are crucial to building problem awareness, which then might be relevant for changes in behavior and the durability of the project. As already described, we found the link between capacity building and problem awareness in the literature (Msengi et al., 2019; Locritani et al., 2019). Also, regarding the interconnection between trust, problem awareness, and change we find similar patterns in the literature. Scholars find that trust in research is an important factor for belief in climate change (Hmielowski et al., 2014) and climate-friendly behavior of individuals (Cologna and Siegrist, 2020), which can be interpreted as problem awareness and change. Further, K Hacker, et al. (Hacker et al., 2012) find that the long-term adoption of health-related interventions by stakeholders was coupled with their capacity. They also find that a lack of trust is a barrier to both the building of capacity and the durability of the interventions.

The role of time in the building of trust is also frequently mentioned in the literature (Weichselgartner and Kasperson, 2010; Berkes, 2009; Levin and Cross, 2004). The overlap of cluster (4) with cluster (2) that contains two further effects of *uptake of knowledge* (uptake in practice and uptake in policy) suggests that the effects of *uptake of knowledge* and *societal effect* and *learning* are connected.

Finally, there are three individual effects that each form their own cluster (3, 5, 6), suggesting that these effects do not clearly link to others. The respective effects—academic outputs, outreach outputs and the capacity building of academic participants—are not mentioned very often for N-S projects (see Fig. 2), which might explain why they do not cluster with other effects (see Fig. 2).

Fig. 4 shows the cluster plot for the North projects. The clusters of effects are different from the clusters observed in Fig. 3, suggesting differences in the interconnections of effects between North and N-S projects. Cluster (1) covers the three effects of the *knowledge production* category: system, target, and transformation knowledge. While this finding shows that the three types of knowledge are often jointly produced within one project, we also observed that they are not connected to other effects, for example, to the effects from the *uptake of knowledge* category. This indicates a potential disconnection between *knowledge production* and its uptake. One explanation could be that transformation and target knowledge produced in TD projects are highly specific and context-dependent. Evidence from several cases (1–4; see Appendix 1) suggests that it is challenging to develop solutions that fit the needs of stakeholders while being generalizable for the re-uptake in science (Wiek et al., 2015).

In cluster (2), uptake of knowledge in practice is linked to effects mostly from the *societal effects* category, namely inclusion, networks, and trust as well as to problem awareness from the *learning* category. Based on this we suggest that *societal effects* and *learning* support the uptake of knowledge for practitioners. Our interpretation maintains that the different beneficial effects are interconnected. Evidence from our coded articles suggests that, for example, uptake of knowledge depends on the network present (Henry and Dietz, 2011), problem awareness (Msengi et al., 2019; Locritani et al., 2019), and the level of trust in the researchers and the research produced (Cologna and Siegrist, 2020). The literature further describes interconnections between, e.g., trust and fostering problem awareness (Hmielowski et al., 2014).

Cluster (3) contains the effects of uptake of knowledge in policy and

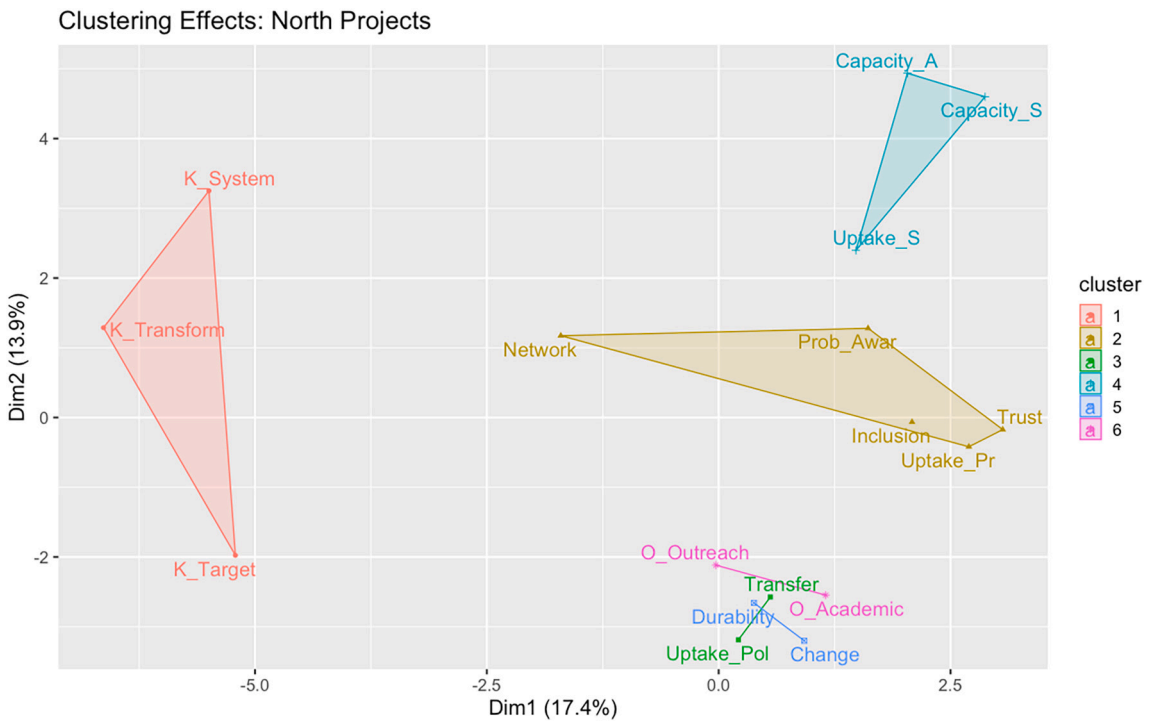

Fig. 4. Cluster results of the effects of North projects.

subsequent transfer. Knowledge that is applicable enough to be taken up in policy also has a higher chance of being transferred to other areas of applications (e.g. different sector). This is nicely illustrated in one of the cases: Hansson and Polk (Hansson and Polk, 2018) (Case 35–39; see Appendix 1) show how new ways of working together developed through the TD project were subsequently taken up in policy and applied in other municipal planning processes:

> *"The most important outcome of the project is a new forum for dialogue and collaboration across sector and administrative borders, including new ways of working together among the municipalities, as well as between and among the regional and national agencies. This new way of working together has created new conditions, structures, contacts, and networks where trust and mutual understanding have been established between a diverse group of civil servants, politicians, and researchers. The concept USC* [Urban Station Communities; name of a TD project in mobility and urban planning] *is now used nationally, and has been integrated in ongoing municipal planning processes." (p. 138).*

Cluster (4) consists of the effects of the capacity building of stakeholders, academic participants, and the uptake of knowledge in science. We assume that capacity building in North projects often happens jointly between stakeholders and academic participants, and that academic participants might use what they have learned in their future research. This is nicely illustrated by Nguyen, et al. (Nguyen et al., 2014) (Case 22; see Appendix 1):

> *"By facilitating the sharing of a rich variety of views and for integrating knowledge among stakeholders, the emergent hybrid knowledge provided farmers with information on the scientific and economic rationale underpinning their decision-making processes; it provided scientists with new ideas for research and researching processes that could lead to a wider adoption of results." (p. 179).*

Cluster (5) covers the *products* category, as it combines academic and outreach outputs. It thus seems that in North projects, there are often concrete outputs planned for all project participants—that is, for both academic participants as well as stakeholders.

Finally, cluster (6) includes the effects change and durability, both from the category *uptake of knowledge*. Our interpretation is that once projects led to actual changes in behavior, effects were also more likely to be sustained beyond project termination. However, both effects were only observed in fewer than 20% of the North projects, which shows that this relationship, while promising, is still rare.

When comparing the similarities between the clustering of the effects of N-S and North projects, we observe two different and one similar pattern. First, for projects within the global North, the three effects of the *knowledge production* category form one single cluster, while for the N-S projects, the three effects of *knowledge production* are combined with *learning* and *societal effects*. This indicates that N-S projects probably place a higher emphasis on inclusion during the production of knowledge, which might then, as a learning experience, increase capacity building of academic participants. Our finding for the North projects is in line with Chambers, et al. (Chambers et al., 2021), who also find that scientific knowledge was negatively correlated with all other types of effects. They suggest that projects that mainly aim to fill knowledge gaps might neglect other effects, especially ones related to implementation, such as collective action or institution-building. This is once again in line with our results for both, N-S and North projects: Neither effects of the *knowledge production* category nor effects from *products* are clustered with any effects of the *uptake of knowledge* category. Second, we observe differences for the effects of change and durability. While both change and durability cluster together in a single cluster for North projects, both are integrated with *learning* and *societal effects* for the N-S projects. Third, the effect of the uptake of knowledge in practice is, for both types of projects, found in the same or a very close cluster as the effects of networks, problem awareness, and trust. This finding shows that these effects are potentially interconnected in both N-S and North projects. Investing in trust-building as well as forming new and strengthening existing networks might thus be effects that reinforce each other and are beneficial for knowledge uptake in TD projects in general.

7. Conclusion

This article explores the differences of effects of TD projects in a N-S setting and TD projects conducted in the global North only. For both

contexts, we have analyzed the prominence of effects and as well as the interconnections between effects. Drawing on the extant literature, we identified five categories of effects (*knowledge production, uptake of knowledge, products, learning, societal effects*) that we used for coding 101 TD projects reported on in the academic literature. We then used descriptive statistics and a clustering approach to analyze how prominently the different effects occur and how the effects relate to each other.

Our analysis suggests that N-S and North projects indeed have different effects. While N-S projects appear to focus more on *societal effects*, North projects score higher on *products*, that is, tangible outputs such as academic publications or outreach material. We also observe that North projects more prominently lead to *knowledge production*, especially the production of transformation knowledge. This result is surprising given that transformation knowledge is strongly linked with TD research and N-S research approaches such as participatory action research (Brutschin and Wiesmann, 2008; Pohl and Hadorn, 2007). As transformation knowledge pertains to ways of reaching targets, it is thus key for bringing about transformation toward sustainable development (Pohl and Hadorn, 2007), and consequently this finding has implications for improving TD research. Nevertheless, the more prominent knowledge uptake in practice and policy in N-S projects shows that North projects can still improve on how they actually use transformation knowledge.

We also observe differences in how effects are interconnected in N-S as compared to North projects. We conclude that N-S projects emphasize inclusion more than North projects do due to a higher awareness of differences between the different participants. This could imply that it is beneficial for North projects to foster inclusion of the different participants to avoid conflicts or misunderstandings, even if participants in North projects seem more homogenous from the outset. For both the N-S and the North projects, we found that the effects from the *knowledge production* category are not strongly related to effects related to the uptake of knowledge. This trade-off was also recently described by other authors who found that the production of knowledge and the involvement of stakeholders are often in conflict with each other (Jahn et al., 2021; Chambers et al., 2021; Newig et al., 2019). However, we also found that for both N-S and North projects, effects belonging to the *uptake of knowledge*, *learning,* and *societal effects* categories are often interconnected.

Our study contributes to the literature in several ways. First, we build on and contribute to the body of literature on transformation toward sustainable development (Schneider et al., 2019a; Muhonen et al., 2019; Fritz et al., 2019) by studying the diverse and interconnected effects of TD projects. By comparing the prominence of different effects of TD projects, we provide an overview of where TD projects perform well and where there is room for improvement. By studying how different effects are interconnected, we confirm, on the one hand, trade-offs already described by other authors. On the other hand, we show that *societal effects*, *learning*, and the *uptake of knowledge* might reinforce each other. Second, by studying how the effects of TD projects differ between N-S and North projects, we contribute to the dialogue on different types of TD projects. We show that there are differences in how prominently the effects are achieved, and in how they are interconnected. Understanding these differences provides insights as to where North projects can learn from N-S projects, and vice versa.

The present study also has several shortcomings. First, it is based on secondary literature only, that is, on findings from publications on TD projects. Thus, we could only analyze the effects described by the authors of the articles. We can, of course, not be certain whether effects that were not described were actually absent, or merely not reported in the publication. Furthermore, we omitted the effects which were not or not sufficiently achieved by a project, even though they belonged to the project objectives. While some of the studied projects reported such effects, it was not possible to gather generalizable data. Theoretical, as well as empirical studies comparing the specified aims of TD projects with those achieved might provide more insights into potential challenges of TD projects. In addition, we only included scientific publications, excluding gray literature such as, e.g., project reports, in our review. Finally, some effect categories were difficult to assess. On the one hand, it was sometimes difficult to understand how and based on what perspective the authors assessed effects such as the uptake of knowledge. On the other hand, as the effects are often strongly interconnected, it was sometimes difficult to disentangle effects where the authors were describing effects from the categories of *learning* or *knowledge production*. With this study, we are only able to describe first patterns of the prominence of different effects of TD projects, their interconnected and the differences of N-S and North projects. Interpreting these patterns further and identifying the underlying reasons requires further research. Future empirical studies on the importance of the different effects based on the perception of academic participants and stakeholders could shed more light on how TD research might contribute to the transformation toward sustainable development.

This article provides the basis for a better understanding of the effects that TD projects have, how they relate to each other, and what differences exist between N-S and North projects. Insofar as TD is claimed to be beneficial for producing holistic and applicable system, target, and transformation knowledge and thus for potentially fostering a transformation toward sustainable development (Schneider et al., 2019a), our systematic analysis provides robust grounds for being able to, first, evaluate how TD projects contribute to sustainable development and, second, to discover ways North projects can learn from N-S projects, and vice versa (Saric et al., 2019; Keitsch and Vermeulen, 2020).

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.

Acknowledgement

Funding: "This work was supported by an ETH Zurich Research Grant".

Appendix 1

Case	North-South vs. North	Topic	Reference
1–4	North	Agriculture/Fisheries	Wiek A, Harlow J, Melnick R, van der Leeuw S, Fukushi K, Takeuchi K, Farioli F, Yamba F, Blake A, Geiger C, et al.: **Sustainability science in action: a review of the state of the field through case studies on disaster recovery, bioenergy, and precautionary purchasing**. *Sustainability Science* 2015, **10**:17–31.
5	North	Sustainable Land Management	Weiss G, Steiner R, Eckmüllner O: **Assessing institutional frameworks of inter-and transdisciplinary research and education**. *Higher Education Policy* 2011, **24**:499–516.
6	North	Urban Planning/Sustainable Cities	

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Case	North-South vs. North	Topic	Reference
			Wang B—C, Chou F—Y, Lee Y-J: **Awareness of Residents Regarding the Construction of a Sustainable Urban Community: A Case Study of Action Research in Taiwan**. *Systemic Practice and Action Research* 2010, **23**:157–172.
7	North	Agriculture/Fisheries	Stephenson RL, Wiber M, Paul S, Angel E, Benson A, Charles A, Chouinard O, Edwards D, Foley P, Lane D: **Integrating diverse objectives for sustainable fisheries in Canada**. *Canadian Journal of Fisheries and Aquatic Sciences* 2019, **76**:480–496.
8	North	Climate Change	Siebenhüner B: **Conflicts in transdisciplinary research: reviewing literature and analysing a case of climate adaptation in Northwestern Germany**. *Ecological Economics* 2018, **154**:117–127.
9	North	Urban Planning/Sustainable Cities	Sharp D, Salter R: **Direct Impacts of an Urban Living Lab from the Participants' Perspective: Livewell Yarra**. *Sustainability* 2017, **9**:1699.
10	North	Agriculture/Fisheries	Schodl K, Leeb C, Winckler C: **Developing science–industry collaborations into a transdisciplinary process: a case study on improving sustainability of pork production**. *Sustainability Science* 2015, **10**:639–651.
11	North	Water & Sanitation	Schneider F, Bonriposi M, Graefe O, Herweg K, Homewood C, Huss M, Kauzlaric M, Liniger H, Rey E, Reynard E: **MontanAqua: tackling water stress in the Alps: water management options in the Crans-Montana-Sierre Region (Valais)**. *GAIA-Ecological Perspectives for Science and Society* 2016, **25**:191–193.
12	North	Climate Change	Schikowitz A: **Creating relevant knowledge in transdisciplinary research projects - Coping with inherent tensions**. *Journal of Responsible Innovation* 2020, **7**:217–237.
13–14	North	Urban Planning/Sustainable Cities	Schäpke N, Omann I, Wittmayer JM, Van Steenbergen F, Mock M: **Linking Transitions to Sustainability: A Study of the Societal Effects of Transition Management**. *Sustainability* 2017, **9**:737.
15	North	Diverse/other	Ruppert-Winkel C, Arlinghaus R, Deppisch S, Eisenack K, Gottschlich D, Hirschl B, Matzdorf B, Mölders T, Padmanabhan M, Selbmann K, et al.: **Characteristics, emerging needs, and challenges of transdisciplinary sustainability science**
16–20	North	Urban Planning/Sustainable Cities	Polk M: **Achieving the promise of transdisciplinarity: a critical exploration of the relationship between transdisciplinary research and societal problem solving**. *Sustainability Science* 2014, **9**:439–451.
21	North	Urban Planning/Sustainable Cities	Perrotti D: **Evaluating urban metabolism assessment methods and knowledge transfer between scientists and practitioners: A combined framework for supporting practice-relevant research**. *Environment and Planning B: Urban Analytics and City Science* 2019, **46**:1458–1479.
22	North	Agriculture/Fisheries	Nguyen TPL, Seddaiu G, Roggero PP: **Hybrid knowledge for understanding complex agri-environmental issues: nitrate pollution in Italy**. *InterNorth Journal of Agricultural Sustainability* 2014, **12**:164–182.
23	North	Diverse/other	Newig J, Jahn S, Lang DJ, Kahle J, Bergmann M: **Linking modes of research to their scientific and societal outcomes. Evidence from 81 sustainability-oriented research projects**. *Environmental Science & Policy* 2019, **101**:147–155.
24	North-South	Water & Sanitation	Leimona B, Lusiana B, van Noordwijk M, Mulyoutami E, Ekadinata A, Amaruzaman S: **Boundary work: Knowledge co-production for negotiating payment for watershed services in Indonesia**. *Ecosystem Services* 2015, **15**:45–62.
25	North	Agriculture/Fisheries	Kawabe M, Kohno H, Ikeda R, Ishimaru T, Baba O, Horimoto N, Kanda J, Matsuyam M, Moteki M, Oshima Y: **Developing partnerships with the community for coastal ESD**. *InterNorth Journal of Sustainability in Higher Education* 2013.
26	North	Diverse/other	Kassab O, Schwarzenbach RP, Gotsch N: **Assessing ten years of inter-and transdisciplinary research, education, and outreach: The Competence Center Environment and Sustainability (CCES) of the ETH Domain**. *GAIA-Ecological Perspectives for Science and Society* 2018, **27**:226–234.
27	North	Energy	Jansujwicz JS, Johnson TR: **The Maine Tidal Power Initiative: transdisciplinary sustainability science research for the responsible development of tidal power**. *Sustainability Science* 2015, **10**:75–86.
28	North	Sustainable Land Management	Huber R, Rigling A: **Commitment to continuous research is a key factor in transdisciplinarity. Experiences from the Mountland project**. *GAIA-Ecological Perspectives for Science and Society* 2014, **23**:256–262.
29	North	Agriculture/Fisheries	Hubeau M, Marchand F, Coteur I, Debruyne L, Van Huylenbroeck G: **A reflexive assessment of a regional initiative in the agri-food system to test whether and how it meets the premises of transdisciplinary research**. *Sustainability Science* 2018, **13**:1137–1154.
30–32	North	Urban Planning/Sustainable Cities	Hessels LK, De Jong SP, Brouwer S: **Collaboration between heterogeneous practitioners in sustainability research: a comparative analysis of three transdisciplinary programmes**. *Sustainability* 2018, **10**:4760.
33–34	North	Sustainable Land Management; Water/Sanitation	Hart DD, Bell KP, Lindenfeld LA, Jain S, Johnson TR, Ranco D, McGill B: **Strengthening the role of universities in addressing sustainability challenges: the Mitchell Center for Sustainability Solutions as an institutional experiment**. *Ecology and Society* 2015, **20**.
35–39	North	Urban Planning/Sustainable Cities	Hansson S, Polk M: **Assessing the impact of transdisciplinary research: The usefulness of relevance, credibility, and legitimacy for understanding the link between process and impact**. *Research Evaluation* 2018, **27**:132–144.
40	North	Sustainable Land Management	Glass JH, Scott AJ, Price MF: **The power of the process: Co-producing a sustainability assessment toolkit for upland estate management in Scotland**. *Land Use Policy* 2013, **30**:254–265.
41	North	Diverse/other	Fritz L, Schilling T, Binder CR: **Participation-effect pathways in transdisciplinary sustainability research: An empirical analysis of researchers' and practitioners' perceptions using a systems approach**. *Environmental Science & Policy* 2019, **102**:65–77.
42	North	Sustainable Resources	Ferguson L, Chan S, Santelmann MV, Tilt B: **Transdisciplinary research in water sustainability: What's in it for an engaged researcher-stakeholder community?***Water Alternatives* 2018, **11**:1.
43	North	Diverse/other	Ernst A, Fischer-Hotzel A, Schumann D: **Transforming knowledge for sustainability: Insights from an inclusive science-practice dialogue on low-carbon society in Germany**. *Energy research & social science* 2017, **29**:23–35.
44	North	Sustainable Land Management	Enengel B, Muhar A, Penker M, Freyer B, Drlik S, Ritter F: **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* 2012, **105**:106–117.
45	North	ICT	Elliot S: **A transdisciplinary exploratory model of corporate responses to the challenges of environmental sustainability**. *Business strategy and the environment* 2013, **22**:269–282.
46	North	Urban Planning/Sustainable Cities	Campbell LK, Svendsen ES, Roman LA: **Knowledge co-production at the research–practice interface: embedded case studies from urban forestry**. *Environmental Management* 2016, **57**:1262–1280.
47	North	Climate Change	

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Case	North-South vs. North	Topic	Reference
			Brink E, Wamsler C, Adolfsson M, Axelsson M, Beery T, Björn H, Bramryd T, Ekelund N, Jephson T, Narvelo W: **On the road to 'research municipalities': analysing transdisciplinarity in municipal ecosystem services and adaptation planning**. *Sustainability science* 2018, **13**:765–784.
48	North	Urban Planning/Sustainable Cities	Bernstein MJ, Wiek A, Brundiers K, Pearson K, Minowitz A, Kay B, Golub A: **Mitigating urban sprawl effects: a collaborative tree and shade intervention in Phoenix, Arizona, USA**. *Local Environment* 2016, **21**:414–431.
49	North	Diverse/other	Beland Lindahl K, Westholm E: **Transdisciplinarity in practice: aims, collaboration and integration in a Swedish research programme**. *Journal of Integrative Environmental Sciences* 2014, **11**:155–171.
50	North	Agriculture/Fisheries	Van Dijk L, Buller HJ, Blokhuis HJ, Van Niekerk T, Voslarova E, Manteca X, Weeks CA, Main DC: **HENNOVATION: Learnings from promoting practice-led multi-actor innovation networks to address complex animal welfare challenges within the laying hen industry**. *Animals* 2019, **9**:24.
51	North	Sustainable Land Management	Reed MG, Godmaire H, Abernethy P, Guertin M-A: **Building a community of practice for sustainability: Strengthening learning and collective action of Canadian biosphere reserves through a North partnership**. *Journal of Environmental Management* 2014, **145**:230–239.
52	North	Agriculture/Fisheries	von Munchhausen S, Haring AM: **Lifelong learning for farmers: enhancing competitiveness, knowledge transfer and innovation in the eastern German state of Brandenburg**. *Studies in Agricultural Economics* 2012, **114**:86–92.
53–56	North-South	Water & Sanitation; Sustainable Land Management	Wolff MG, Cockburn JJ, De Wet C, Carlos Bezerra J, Weaver MJT, Finca A, De Vos A, Ralekhetla MM, Libala N, Mkabile QB, et al.: **Exploring and expanding transdisciplinary research for sustainable and just natural resource management**. *Ecology and Society* 2019, **24**.
57–59	North-South	Energy	Wiek A, Harlow J, Melnick R, van der Leeuw S, Fukushi K, Takeuchi K, Farioli F, Yamba F, Blake A, Geiger C, et al.: **Sustainability science in action: a review of the state of the field through case studies on disaster recovery, bioenergy, and precautionary purchasing**. *Sustainability Science* 2015, **10**:17–31.
60	North-South	Agriculture/Fisheries	Trimble M, Plummer R: **Participatory evaluation for adaptive co-management of social–ecological systems: a transdisciplinary research approach**. *Sustainability Science* 2019, **14**:1091–1103.
61	North-South	Energy; Urban Planning/ Sustainable Cities	Thomas S, Richter M, Lestari W, Prabawaningtyas S, Anggoro Y, Kuntoadji I: **Transdisciplinary research methods in community energy development and governance in Indonesia: Insights for sustainability science**. *Energy Research & Social Science* 2018, **45**:184–194.
62–66	North-South	Energy	Tejada G, Cracco M, Bouleau CR, Bolay J-C, Hostettler S: **Testing Analytical Frameworks in Transdisciplinary Research for Sustainable Development**. *Sustainability* 2019, **11**:4343.
67	North-South	Sustainable Resources	Taylor PL, Cronkleton P, Barry D: **Learning in the Field: Using Community Self Studies to Strengthen Forest-Based Social Movements**. *Sustainable Development* 2013, **21**:209–223.
68–71	North-South	Sustainable Land Management; Water/Sanitation	Siew TF, Aenis T, Spangenberg JH, Nauditt A, Döll P, Frank SK, Ribbe L, Rodriguez-Labajos B, Rumbaur C, Settele J, et al.: **Transdisciplinary research in support of land and water management in China and Southeast Asia: evaluation of four research projects**. *Sustainability Science* 2016, **11**:813–829.
72–73	North-South	Urban Planning/Sustainable Cities	Seymoar N—K, Ballantyne E, Pearson CJ: **Empowering residents and improving governance in low income communities through urban greening**. *InterNorth Journal of Agricultural Sustainability* 2010, **8**:26–39.
74	North-South	Diverse/other	Schneider F, Giger M, Harari N, Moser S, Oberlack C, Providoli I, Schmid L, Tribaldos T, Zimmermann A: **Transdisciplinary co-production of knowledge and sustainability transformations: Three generic mechanisms of impact generation**. *Environmental Science & Policy* 2019, **102**:26–35.
75	North-South	ICT	Sarrica M, Denison T, Stillman L, Chakraborty T, Auvi P: **"What do others think?" An emic approach to participatory action research in Bangladesh**. *AI & SOCIETY* 2019, **34**:495–508.
76	North-South	Sustainable Resources	Ruankaew N, Le Page C, Dumrongrojwattana P, Barnaud C, Gajaseni N, van Paassen A, Trébuil G: **Companion modelling for integrated renewable resource management: a new collaborative approach to create common values for sustainable development**. *InterNorth Journal of Sustainable Development & World Ecology* 2010, **17**:15–23.
77–78	North-South	Sustainable Land Management	Roux DJ, Nel JL, Cundill G, O'Farrell P, Fabricius C: **Transdisciplinary research for systemic change: who to learn with, what to learn about and how to learn**. *Sustainability Science* 2017, **12**:711–726.
79	North-South	Sustainable Land Management	Rodriguez Lopez JM, Tielbörger K, Claus C, Fröhlich C, Gramberger M, Scheffran J: **A Transdisciplinary Approach to Identifying Transboundary Tipping Points in a Contentious Area: Experiences from across the Jordan River Region**. *Sustainability* 2019, **11**:1184.
80	North-South	Agriculture/Fisheries	Restrepo MJ, Lelea MA, Kaufmann BA: **Assessing the quality of collaboration in transdisciplinary sustainability research: Farmers' enthusiasm to work together for the reduction of post-harvest dairy losses in Kenya**. *Environmental Science & Policy* 2020, **105**:1–10.
81	North-South	Diverse/other	Oyinlola M, Whitehead T, Abuzeinab A, Adefila A, Akinola Y, Anafi F, Farukh F, Jegede O, Kandan K, Kim B, et al.: **Bottle house: A case study of transdisciplinary research for tackling global challenges**. *Habitat InterNorth* 2018, **79**:18–29.
82	North-South	Agriculture/Fisheries	Neef A: **Fostering Incentive-Based Policies and Partnerships for Integrated Watershed Management in the Southeast Asian Uplands**. *Southeast Asian Studies* 2012, **1**:247–271.
83	North-South	Water & Sanitation	Maheshwari B, Varua M, Ward J, Packham R, Chinnasamy P, Dashora Y, Dave S, Soni P, Dillon P, Purohit R, et al.: **The Role of Transdisciplinary Approach and Community Participation in Village Scale Groundwater Management: Insights from Gujarat and Rajasthan, India**. *Water* 2014, **6**:3386–3408.
84–85	North-South	Urban Planning/Sustainable Cities	Marshall F, Dolley J, Priya R: **Transdisciplinary research as transformative space making for sustainability**. *Ecology and Society* 2018, **23**.
86	North-South	Sustainable Land Management	Lund S, Banta GT, Bunting SW: **Applying stakeholder Delphi techniques for planning sustainable use of aquatic resources: experiences from upland China, India and Vietnam**. *Sustainability of Water Quality and Ecology* 2014, **3**:14–24.
87	North-South	Agriculture/Fisheries	Jagustović R, Zougmoré RB, Kessler A, Ritsema CJ, Keesstra S, Reynolds M: **Contribution of systems thinking and complex adaptive system attributes to sustainable food production: Example from a climate-smart village**. *Agricultural systems* 2019, **171**:65–75.
88	North-South	Diverse/other	Jacobi J, Llanque A, Bieri S, Birachi E, Cochard R, Chauvin ND, Diebold C, Eschen R, Frossard E, Guillaume T: **Utilization of research knowledge in sustainable development pathways: insights from a transdisciplinary research-for-development programme**. *Environmental science & policy* 2020, **103**:21–29.
89	North-South	Diverse/other	Eitzel M, Hove EM, Solera J, Madzoro S, Changarara A, Ndlovu D, Chirindira A, Ndlovu A, Gwatipedza S, Mhizha M: **Sustainable development as successful technology transfer: Empowerment through teaching,**

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Case	North-South vs. North	Topic	Reference
			learning, and using digital participatory mapping techniques in Mazvihwa, Zimbabwe. *Development Engineering* 2018, **3**:196–208.
90–91	North-South	Agriculture/Fisheries	Douthwaite B, Hoffecker E: **Toward a complexity-aware theory of change for participatory research programs working within agricultural innovation systems**. *Agricultural systems* 2017, **155**:88–102.
92	North-South	Agriculture/Fisheries	Davies J, Maru Y, Hall A, Abdourhamane IK, Adegbidi A, Carberry P, Dorai K, Ennin SA, Etwire PM, McMillan L: **Understanding innovation platform effectiveness through experiences from west and central Africa**. *Agricultural Systems* 2018, **165**:321–334.
93	North-South	Agriculture/Fisheries	Dangles O, Carpio F, Villares M, Yumisaca F, Liger B, Rebaudo F, Silvain J-F: **Community-based participatory research helps farmers and scientists to manage invasive pests in the Ecuadorian Andes**. *Ambio* 2010, **39**:325–335.
94	North-South	Agriculture/Fisheries	Brent L: **Participation and Compliance in Tension: Developing Women-led Yarn Spinning Businesses in Tajikistan**. *The Journal of Development Studies* 2020, **56**:1295–1308.
95	North-South	Water & Sanitation	Brennan M, Rondón-Sulbarán J: **Transdisciplinary research: Exploring impact, knowledge and quality in the early stages of a sustainable development project**. *World Development* 2019, **122**:481–491.
96–100	North-South	Agriculture/Fisheries	Belcher BM, Claus R, Davel R, Ramirez LF: **Linking transdisciplinary research characteristics and quality to effectiveness: A comparative analysis of five research-for-development projects**. *Environmental Science & Policy* 2019, **101**:192–203.
101	North-South	Energy	Ambole A, Musango JK, Buyana K, Ogot M, Anditi C, Mwau B, Kovacic Z, Smit S, Lwasa S, Nsangi G: **Mediating household energy transitions through co-design in urban Kenya, Uganda and South Africa**. *Energy Research & Social Science* 2019, **55**:208–217.

Appendix 2

This table gives an example of a text excerpt for each effect.

	Effect (Abbreviation)	Example text excerpt	Reference
Knowledge Production	**System knowledge** (K_System)	The application of the Mode 2 research approach through the integration of a participatory process into biophysical studies provided added value for a more comprehensive understanding of the nitrate issue, by taking into account a wider range of factors that influence management decisions and practices in inter-dependent farms. We argue that such an understanding couldnot emerge from just the experimental results and the transfer of information from scientists to others.	(Nguyen et al., 2014)
	Target knowledge (K_Target)	When modelling the future, the research team considered regional climatescenarios as well as four scenarios – derivedfrom collaboration with regional stakeholders of possible societal and economic development.	(Schneider and Rist, 2014)
	Transformation knowledge (K_Transform)	Due to the participatory approach, research findings were translated into management practice. Community foresters now call every resident after tree delivery, and automated emails send seasonal tree care tips; such follow-up communication was previously resident-driven and infrequent.	(Campbell et al., 2016)
Uptake of Knowledge	**Uptake in Practice** (Uptake_Pr)	Both communities developed and implemented their Green Plans to create productive green spaces, including community gardens, shade trees and the planting of 20 new local species.	(Seymoar et al., 2010)
	Uptake in Policy (Uptake_Po)	the initiation of a process by which tribal governments in Maine and the U.S. Department of Agriculture Animal and Plant Health Inspection Service (USDA-APHIS) can develop a memorandum of understanding to ensure quick and collaborative responses to infestations.	(Hart et al., 2015)
	Uptake in Science (Uptake_S)	Stakeholder engagement advances scientific discovery by incorporating stakeholder knowledge and questions into scientific studies in a way that research teams would not have done alone. Stakeholders provided feedback on questions, model parameter assumptions, output metrics, modelling scenarios and interpretations in WW2100.	(Ferguson et al., 2018)
	Change in practices (Change)	After learning new cause–effect relations from their experiments, farmers changed their practices. As such, monitoring activities served to sustain enthusiasm as farmers noticed positive progress.	(Restrepo et al., 2020)
	Sustainability of project (Sust)	In all three projects, there have been benefits to the community that have been sustained over time. As noted, the Bangkok communities are still working on environment issues together eight years later due to the combination of a growing grassroots culture of environmental concern, support from the national environmental NGO and municipal funding.	(Seymoar et al., 2010)
	Transfer of results (Transfer)	This knowledge was also used to establish water governance systems at different levels (i.e. village level, communities surrounding the lake, and the nagari forum in Singkarak; a community forestry scheme at the watershed level and conditional corporate social responsibility by the HEP company in the riparian zone in Sumberjaya)	(Leimona et al., 2015)
Products	**Academic Outputs** (O_Academic)	In terms of output the project has produced a set of desk-studies to increase theoretical grounding and integrate previous research around social sustainability. Project participants have disseminated and discussed project results at several workshops and external conferences.	(Hansson and Polk, 2018)
	Outreach Outputs (O_Outreach)	This work also helped create revised ordinances that account for a changing climate, as well as education materials to improve citizen-level stewardship.	(Hart et al., 2015)
Learning	**Problem awareness** (Prob_Awar)	Dairy farmers could relate to the risk that toxic cyanobacteria pose to their cows and hence the dangers associated with nutrient enrichment of farm dams. It was also rewarding to learn that, following one of the dialogues, a farmer had sourced further reading on the tragedy of the commons and that the concept has helped him to better understand social–ecological challenges in the area.	(Roux et al., 2017)
	Capacity Building (Capacity_A; Capacity_S)	Other positive effects were the opportunity for young researchers to gain confidence and experience through repeated meetings with the project group, including opportunities to collaborate withpractitioners and gain support from senior researcher.	(Brink et al., 2018)
Societal Effects			(Roux et al., 2017)

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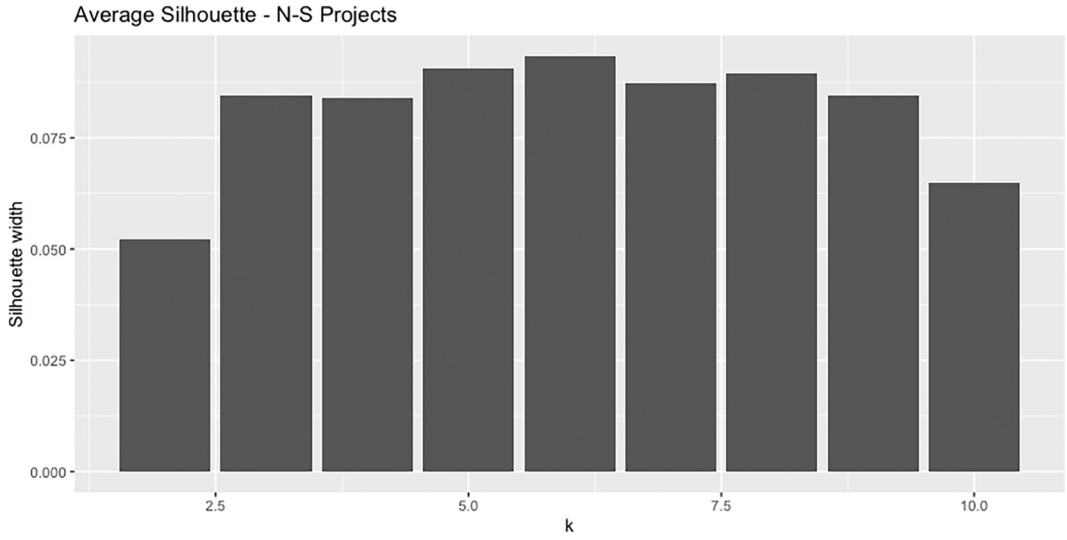
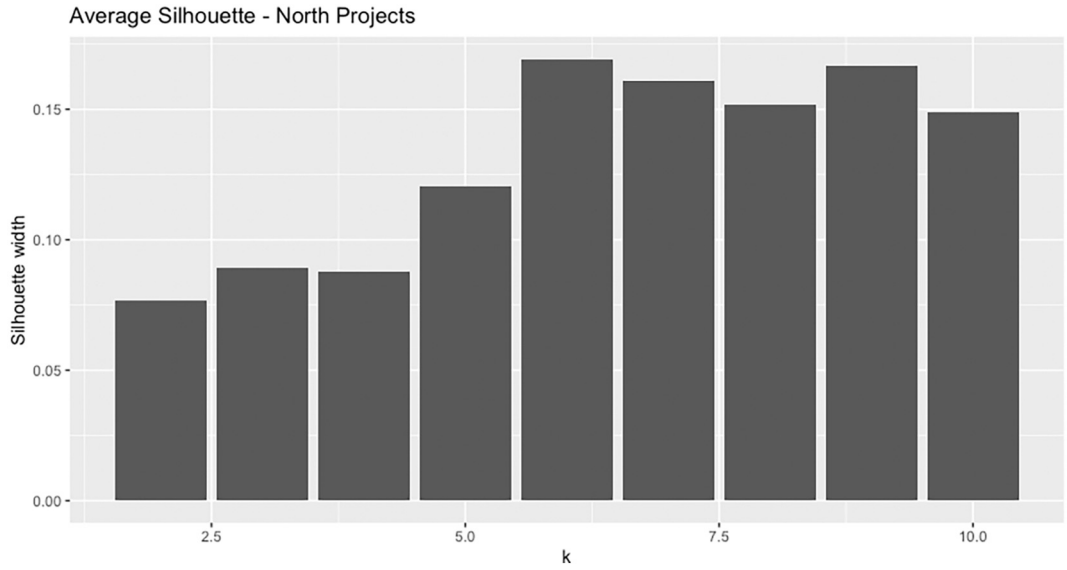
	Effect (Abbreviation)	Example text excerpt	Reference
	Building trust (Trust)	A general characteristic of both case studies was thatscientists respectfully and empathetically listened to theirtransdisciplinary learning partners. Such listening helped to remove social distance and build trust among participants.	
	Networks & Relationships (Network)	At NGInfra, the interactions with practitioners have helped to improve the relevance of the research capacity and to develop a cross-sectoral network. This network has continued to exist after the programme ended. Six practitioners have initiated a follow-up programme and there are still follow-up projects outside the programme with funding from other schemes.	(Hessels et al., 2018)
	Inclusion (Inclusion)	Farmers developed their own trials to test practices to improve milk quality and to buffer seasonality based on different feeding strategies. Fig. 1a shows a high percentage of participation, whereby farmers had the freedom to decide what they wanted to test. On average, 75% of the farmers participated in the farmer-led experimentations, and 90% inthe monitoring activities. This created a sense of ownership of the process of experimenting that also contributed toward sustaining their autonomy.	(Restrepo et al., 2020)

Appendix 3

Average silhouette plots for the data of the N-S projects and the domestic projects.





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