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Transdisciplinary co-creation increases the utilization of knowledge from sustainable development research

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ABSTRACT

Our study aimed at understanding the utilization of research knowledge generated in sustainable development research. Drawing on a sample of 54 recent research projects, we investigated how and by whom the knowledge was used, what changes were achieved, and how non-academic actors were involved. As a conceptual framework we combined a concept of "stages of knowledge utilization" with a spiral model that co-creates three forms of knowledge – systems knowledge, target knowledge, and transformation knowledge, and which spans from joint problem definition to concrete sustainability transformations. We analysed questionnaires from 94 academic and non-academic actors using cross-tabulation, chi-squared tests, and qualitative content analysis. The early involvement of non-academic actors from key groups such as local enterprises was positively related to the utilization of research knowledge, as was their involvement in diverse roles. However, only little of the research knowledge generated has so far resulted in changes in policy and practice, partly because sustainability transformations are larger societal processes. Utilization of research knowledge for sustainability transformations cannot be achieved without employing a transdisciplinary approach that brings together academic and non-academic actors in a setting that enables discussions on an even footing and the empowering of actors who are often not heard. In such settings, researchers are also part of the change rather than mere observers, an additional factor that came up in our participatory results validation activities and that requires further research. For more influence on policies and practice, research for development requires active participation of non-academic actors from the outset, when the project contents are defined.

1. Introduction

Scientific research across disciplines is important in creating the necessary knowledge, innovations, practices, and technologies that build foundations of sustainable development (Lang et al., 2012; Clark et al., 2016; van der Hel, 2016; Brennan and Rondón-Sulbarán, 2019). There is however no consensus on how science actually contributes to sustainability (Hansson and Polk, 2018; Belcher et al., 2020). Furthermore, there is no consensus on how to actually do transformative science that contributes to sustainability and equity (Thompson et al., 2017; Hansson and Polk, 2018; Schneider et al., 2019a,2019b).

The questions of how, by whom, and for what knowledge from scientific research is used for the benefit of society has long been investigated in the context of impact evaluation, follow-up research, and

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similar approaches (Larsen, 1980; Kerkhoff and Lebel, 2006; Nilsen et al., 2013; Kläy et al., 2015; Verwoerd et al., 2020). But assessments have often focused on what happens when knowledge has already been created, in a sense of "putting it out there" (Nagy et al., 2020). Yet, utilization of knowledge already happens while it is being generated, and even to a greater degree if it is co-created among academic and non-academic actors (Hoffmann et al., 2019; Jacobi et al., 2020). Such transdisciplinary ways of doing science have become important in the co-creation of knowledge to address complex societal challenges (Lang et al., 2012; McGregor, 2015; Polk, 2015; van der Hel, 2016; Brennan and Rondón-Sulbarán, 2019). Transdisciplinarity involves systematic integration and co-creation of knowledge that transcends identity boundaries of, for instance, gender, race, ethnicity, and class, and focuses on holistic problem-solving frameworks (Alvargonzález, 2011; Nicolescu, 2014; Frodeman, 2017).

We understand the "utilization of research knowledge" as an indication for impacts towards sustainability transformations. For this purpose, existing yet limited frameworks can be broadened and adapted, developing former linear thinking (Landry et al., 2001) towards more synchronic or systems thinking. Our previous study (Jacobi et al., 2020) identified a link between the research knowledge utilization as proposed by Landry et al. (2001) and five focal areas in transdisciplinary research: inclusion, collaboration, usability, integration, and reflexivity (Polk, 2015). The study maps different stages of utilizing research knowledge according to different geographical scales and identifies co-creation of knowledge by different actors as the most useful mechanism to achieve transformation, as perceived by people involved in the studied projects (Jacobi et al., 2020). Our previous results showed that knowledge utilization does not happen along a linear pathway but at multiple stages simultaneously. Another study using a subsample of the same project base (Eschen et al., 2021) found that research knowledge utilization was significantly higher in longer projects of six years than in shorter projects of two to three years, pointing to the importance of the *processes* that these projects induce or enhance.

Much progress has been made in conceptualizing transdisciplinarity (TD), providing TD theories and concepts for sustainability transformation and contribution to the United Nations Sustainable Development Goals (SDGs). However, the lack of larger data sets undermines empirical verification. This study therefore set out to investigate the experiences of 54 research for development projects from the 10-year Swiss Program for Research on Global Issues for Development (r4d program). The r4d program included five thematic modules (ecosystems, food security, social conflict, employment, public health) and one thematically open module. The projects shared strategic, scientific, and development objectives as set by the funding agencies, the Swiss Agency for Development and Cooperation and the Swiss National Science Foundation. Projects were asked to use a transdisciplinary approach, which was, however, not further defined. Our overall aim was to analyse the research activities and processes leading to the widespread utilization of co-created knowledge by a broad range of actors. Our guiding hypothesis was that there is a positive relationship between the utilization of research knowledge (and associated changes in science, policy, and practice) and a transdisciplinary project process. Specifically, we aimed to answer the following research questions:

1) What stages of the utilization of research knowledge were reached, with whose contributions, by whom, and with what effects?
2) What were the knowledge co-creation processes that the projects followed?
3) What are the most important context factors that influence the utilization of research knowledge?

2. Conceptual framework

Transdisciplinarity as a research for development approach – in which knowledge to tackle life-world problems is co-created among academic and non-academic actors such as practitioners (Hirsch Hadorn et al., 2008) – is receiving increased attention as an important methodology for sustainability transformations (Wuelser et al., 2020). We regard transformation as "*alterations of society's systemic characteristics and encompassed social, cultural, technological, political, economic, and legal change*" (Driessen et al., 2013, cited in Brand, 2016), requiring an "*analysis of dominant trends that pursue (…) the obstacles of social-ecological transformation and the positive as well as failed experiences to overcome them*" (Brand, 2016). Thus, transformation is linked to the idea of empowering marginalized actors to participate in these transformations, as well as to the possibilities of redefining priorities, key topics, and goals (Marshall et al., 2018; Tembo et al., 2021). Or, as Schneider et al. (2019a) put it, "*an emancipatory process of structural change involving alterations of worldviews, values, agency, power relations, social networks, ecosystems, and physical infrastructure*". In this sense, the participation of different actors in sustainability transformation projects adds *consequentiality* to the process, which refers to the possibility of the participants influencing the outcomes (Dryzek, 2009; Wamsler, 2017). Going beyond *consultation*, participation then also means participation in knowledge co-creation, as well as in decision-making (Polk, 2015; Rosendahl et al., 2015). "Research knowledge" can broadly refer to the knowledge that emerges from research projects in different forms and expressions. What is important is that its utilization transgresses the realm of academic research teams and includes social actors who are not necessarily directly involved in the research in co-production and dissemination (Eschen et al., 2021). Based on our previous findings that the utilization of research knowledge happens simultaneously at different stages (Jacobi et al., 2020), we built on the stage-based framework by Landry et al. (2001). This framework was already linked to transdisciplinarity and made circular by Hoffmann et al. (2019). In order to strengthen the non-linear character and the multiple ways in which research knowledge can affect societal transition, we further broadened the existing stages by adding *Communication* to *Transmission,* to emphasize that this is not a unidirectional process, and by adding Replication to *Application* of co-creation processes (Hoffmann et al., 2019). We also added new stages, building on recent literature on transdisciplinary co-creation of knowledge (Table 1): *Empowerment* of stakeholders through intensive collaboration (Schmidt et al., 2018, Chambers et al., 2021), a focus on marginalized communities and

Table 1
Stages of the utilization of research knowledge based on Landry et al. (2001)

Stage	Explanation
Cognition	When actors access and understand research knowledge.
Transmission/ communication	An exchange of research knowledge among academic and non-academic actors. This can happen in both directions.
Social learning	A cognitive process that takes place in a social context and can occur purely through observation or direct instruction, as a result of an exchange and/or teaching process.
Reference	When third parties refer to and cite research knowledge and its sources.
Empowerment	A process of gaining power and learning how to achieve this, whereby people, groups, and communities acquire mastery of their own lives.
Influence	When the research knowledge influences choices and decisions of others (e.g., when key messages and findings are used in guidelines, regulations, or directives).
Building trust	When using the knowledge from the project (partners) increases the credibility of others, e.g., linked to collective historical memories and the culture of legality, and a rational perception that depends on the information to which one has access and the immediate context of interaction.
Application/ replication	When the research knowledge is applied and gives rise to new joint knowledge production and application cycles.
Effort	When different actors (e.g., policymakers, scientists, or local communities) make efforts to adopt and make use of research knowledge.
Redefinition	Redefining or reframing issues, goals, and concepts.

subaltern knowledge (Marshall et al., 2018), and ideally also sharing decision-making power regarding e.g. contents and budget; *Social learning* (Clark et al., 2016; Schneider et al., 2019a,2019b; Wenger-Trayner and Wenger-Trayner, 2020); *Building trust* (Tobias et al., 2019); and *Redefinition*, which refers to collectively questioning and reframing narratives, issues, goals, and concepts (Chambers et al., 2021). While our categories can also be understood as a typology of different uses and influences of research, we retain the term "stages", to indicate that we are adapting a previous concept by Landry et al. (2001). We apply these stages in a non-linear fashion, i.e., conceptualizing them in no particular order or hierarchy and allowing for different sequences, consecutive or simultaneous, or for omissions. At the same time, we acknowledge that some of them are cumulative or even conditional to reaching another stage (e.g., *Empowerment* for the *Redefinition* of issues and concepts). This means that we do not assume that research knowledge is utilized more because of reaching a given stage, but when more stages are involved. As the stages are diverse, we also assume that the more of them are included, the more likely is their contribution to sustainability transformations as defined above.

We broadly distinguish between five societal areas through which the utilization of research knowledge can occur (Table 2). The five areas – situated within science, policy, and practice – do not include all possible effects of knowledge utilization, but rather build on the idea of "stages", to explain how research knowledge from a (transdisciplinary) scientific process reaches society. We do not assume that knowledge utilization always affects these societal areas, nor do we analyse the direct impact of the Swiss r4d projects on sustainability transformations. We included the five societal areas to be able to link the project processes to them, and because the impact of transdisciplinary science on policy and practice is a widely discussed field, as is the influence of transdisciplinarity on science itself (Enengel et al., 2012; Moser, 2016).

Scholars have long argued that integral transformations of structures and institutions require the adoption of holistic and integrative perspectives for the co-creation of knowledge among different actors (Max-Neef, 2005; Hirsch Hadorn et al., 2006; Wiesmann, 2008). Based on this literature, Rist and Herweg (2016) proposed an understanding of a transdisciplinary co-creation cycle in research and development projects as a spiral in five steps (Fig. 1): (1) joint definition of the problem and contents of the project or initiative; (2) integration of natural and social sciences; (3) integration of non-academic actors and their knowledge; (4) a social learning process and joint reflection on the goals; and (5) collective action for implementation (Rist and Herweg, 2016). Building on our previous study (Jacobi et al., 2020), which, as mentioned in the introduction, linked Landry et al.'s stages with Polk's five focal areas of transdisciplinary research, we use the spiral to illustrate the combined stages and focal areas in a dynamic, evolving process. Such a process may influence all the stages of utilization of research knowledge presented in Table 1. While scholars have focused on how knowledge flows between different actors in TD research (Barreteau et al., 2010, 2018), our framework emphasizes a societal process of which TD research is part, that ranges from the co-creation of knowledge to its application in societally relevant fields. Our framework takes into account the frameworks presented by Jahn et al. (2012) and Hoffmann et al. (2019), but it makes stakeholder empowerment through social learning more explicit, and further includes collective action and implementation as part of the process.

Transdisciplinary research not only unites different epistemologies;

Table 2
Five societal areas and potential effects of utilizing research knowledge

Science – developing/testing new tools and methods
Science – new insights
Policy – influence on policy agenda, discourses etc.
Policy – changes in regulations, norms, or conventions
Practice – behavioral change, e.g. adoption of a new technology

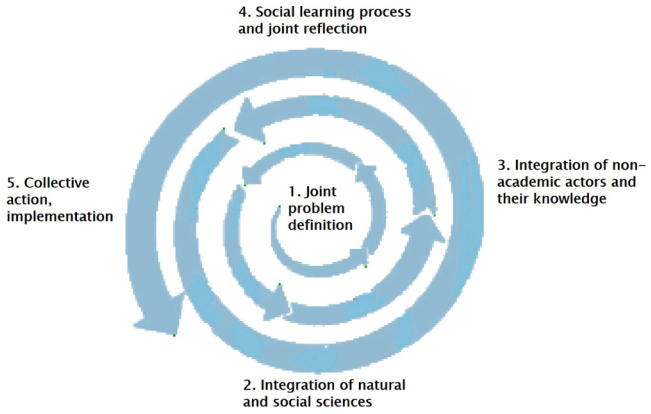

Fig. 1. A spiral showing a transdisciplinary co-creation cycle of transformation in five steps (based on Rist and Herweg, 2016).

it also co-creates at least three different forms of knowledge (Pohl, 2011; Schneider et al., 2019a,2019b), to which the five steps in Fig. 1 are related: target knowledge (normative knowledge, represented in steps 1 and 4); systems knowledge (in the form of empirical knowledge, represented in steps 2 and 3); and transformation knowledge (on how a sustainability problem can be addressed, represented in steps 4 and 5) (Hirsch Hadorn et al., 2006, 2008). This means that ideally, reflection on the norms and targets happens already at the beginning and during the project, and thus implementation and transformation are preceded by a reflective and empirical process. We employ this concept of three forms of knowledge to characterize the knowledge that is being co-created and used in the sample. The stages of utilization from Table 1 and the areas of effects from Table 2 may occur in any part of the spiral; the spiral links the stages of knowledge utilization to a process of reflection (steps 1 and 4), inclusion (steps 2 and 3), and co-creation (all five steps).

3. Methods

We used a three-step approach to investigate the utilization of research knowledge generated through a total of 54 research projects. All projects were either finished or in their second half. An overview of all projects can be found in Supplementary Material I. First, we administered a survey to all project teams, targeting at least two academic and two non-academic team members of each project. Second, we analysed the qualitative and quantitative data using both descriptive and inferential statistics respectively. Third, we conducted a results validation workshop with interested participants from the projects.

3.1. Survey

We administered an online questionnaire (see Supplementary Material II) with 23 open and closed (multiple choice) questions using the online survey tool Kobotoolbox (www.kobotoolbox.com) to all project teams. The survey was prefaced with an introduction explaining the amended stages of knowledge utilization, but we intentionally left open the meaning of "knowledge", acknowledging that "knowledge", including research knowledge, has many different forms and expressions. We tried to obtain at least two answers per project, one from an academic and one from a non-academic actor. The survey had four parts: (1) general, project-related questions; (2) questions on knowledge utilization (e.g. who are the actors that participate in the projects and contribute to the co-creation of knowledge?); (3) questions on the project processes (i.e., how the projects work); and (4) control questions on the projects' context and external influence. The questionnaire employed Likert scales (e.g., "no", "weak", "medium", or "strong" effects on changes in science, policy, and practice) as well as rankings (e.g., from weak to strong contributions) and open questions for qualitative

answers. We administered a shorter but comparable questionnaire to non-academic actors who were involved in (e.g., as consortium partners) or connected to the projects (e.g. as implementation partners), with questions about the respondents' roles, and questions on parts 1, 3, and 4 (Supplementary Material III). We controlled for contextual factors by asking respondents to identify and rank factors that could enable or hinder knowledge utilization. Supplementary Material IV provides an overview on the respondents and their roles in the respective projects.

3.2. Data analysis

We analysed the obtained information in three steps: (1) descriptive statistics for quantitative results, including contingency tables; (2) significance tests on interrelations; and (3) a qualitative content analysis. This allowed to answer research question 1, describing the multiple stages of utilization of knowledge achieved by the projects. For research question 2, we tested possible relationships between the project processes and the utilization of research knowledge (with the stages from Table 1 as response variables) using cross-tabulation and chi-squared tests. Qualitative data were analysed using content analysis with both deductive and inductive codes from the responses. The relationships that were tested at 0.05 significance level included (1) a possible link between the stage of knowledge utilization and a contribution by specific actors (compiled during a portfolio analysis of the projects (Jacobi et al., 2020)); (2) possible links between knowledge utilization and changes in science, policy, and practice; and (3) the roles of the non-academic actors participating in the project influencing utilizing research knowledge. Supplementary Material V provides an overview of the statistical results. Since the number of answers per project varied and showed different perspectives, we analysed the answers at individual level instead of at project level, similarly to Zscheischler et al. (2018). Against the results, we assessed the guiding hypothesis – that there is a positive relationship between transdisciplinary processes and research knowledge utilization, leading to transformations towards sustainable development (i.e. changes in science, policy, and practice) – and explain what this relationship is in the discussion section.

3.3. Validation of results

After analysing the data, we organized an online validation workshop with project representatives for a presentation and discussion of the main results in the context of the concrete experiences made in the projects. Twenty-one people participated and related the results to their own project experience.

4. Results

4.1. Overview

We received and analysed 94 answers from 43 out of 54 research for development projects from all five thematic modules. They reported activities in 37 countries. 39% of the answers are for project activities and experiences in Africa, 28% for Asia, 16% for Europe, and 12% for Latin America. Twenty-one respondents were principal investigators, 18 were co-principal investigators, 20 were project coordinators, 17 respondents were non-academic actors that were involved in the respective projects, and the remaining 18 respondents were researchers in different functions. Project goals most frequently mentioned were inductively coded as (1) *to generate new knowledge (mainly scientific)*, (2) *to learn, share, and validate together*, and (3) *to enhance people's capabilities*. Just over half (52.1%) of the answers confirmed contribution to sustainability transformations, while 38.3% of the responses indicated that they did not know, or considered it too early to say.

4.2. Stages, actors, and effects

4.2.1. Stages of knowledge utilization achieved

The most frequently achieved stages were *Cognition* and *Transmission/communication* (both 16.7%), inside and outside the academic sphere, as illustrated by the quote "*most of the recent activities are rather 'conventional' research which is aimed for eventual publication in international journals, while also providing a basis for exchanges (discussions with/among stakeholders, policy reviews)*". The least achieved stage was *Empowerment* (4.2%). The other stages in between included, for instance, *Application/replication* at 10.1% and *Building trust* at 6.5%.

One example of a high level of knowledge utilization was from a project involving smallholder farmers in West Africa. The project aimed at co-developing acceptable and sustainable crop management options for yam-based farming systems in Burkina Faso and Côte d'Ivoire. In addition to academic researchers, the project involved yam farmers, traders, transporters, yam processors, agricultural extension agents, input suppliers, media, microfinance institutions, and security agents, as well as traditional, religious, and administrative authorities who regularly met on so-called "innovation platforms". After a joint definition of the problems to be tackled, the actors co-created innovative crop management options and evaluated them in a continuous feedback loop approach. They then discussed/validated these options with further actors at the local scale (i.e. on the project sites). These innovation platforms also enabled actors to communicate on the results of the project. The approach and innovations developed in the project have been deployed and used outside the original project sites in Côte d'Ivoire (Kiba et al., 2020). Another example, albeit one with a lower level of knowledge utilization, comes from a project working on illicit financial flows in and between Lao PDR, Switzerland, and Ghana. The project aimed at contributing to sustainability transformation, creating new knowledge, and developing and testing new tools. Non-academic participants were local and international private enterprises; they were involved after securing funding and towards the end of the project. The stages of knowledge utilization reported in this project were *Cognition*, *Transmission/communication*, and *Social learning*. The project had a strong effect on developing and testing new tools and methods, a medium effect regarding scientific insights, and a weaker effect on policy change. No changes in practice were reported. These examples may illustrate different approaches and different levels of knowledge utilization, but a direct comparison is not possible due to the different roles of the respondents, the different topics addressed, and the different contexts in which the projects took place.

4.2.2. Actors' contribution to the utilization of research knowledge

We could not find a significant relationship between the number of different actors involved and the number of stages reported (Fig. 2). However, the number of roles the actors played in the projects vis à vis the number of stages (Table 1) reported was significant ($p = 0.03$). This finding points to the importance of the quality of participation instead of the quantity of different actors involved in the projects. We found significant relationships – visualized in Fig. 2 – between the stages of knowledge utilization and the participation of specific actors in terms of their contribution to the co-creation of knowledge. *National research institutions* such as universities highly contributed to *Transmission/communication* ($p = 0.001$), *Influence* ($p = 0.005$), and *Cognition* ($p = 0.014$), while *Local NGOs and/or extension agencies* had a significant association with *Building trust* ($p = 0.001$), *Empowerment* ($p = 0.005$), *Cognition* ($p = 0.002$), and *Influence* ($p = 0.032$). *Community economic organizations* were associated with *Application/replication* ($p = 0.036$). *Local communities* were also linked to *Application/replication* ($p = 0.008$), and in addition to *Social learning* ($p = 0.001$), *Building trust* ($p = 0.018$), and *Empowerment* ($p = 0.000$). *Community governance organizations* ($p = 0.028$), *Local private enterprises* ($p = 0.036$), *Local communities* ($p = 0.049$), and *Women's groups* ($p = 0.045$) were significantly associated with the utilization stage of *Redefining issues. Local private enterprises*

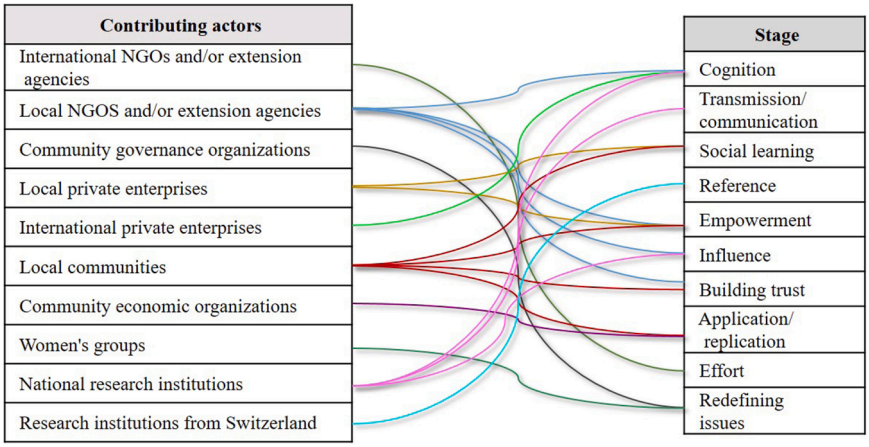

Fig. 2. Significant relationships between specific groups of actors participating in the r4d projects and contributing to the co-creation of knowledge and the stages of utilization of research knowledge.

were linked to *Empowerment* ($p = 0.003$), *Social learning* ($p = 0.025$), and *Redefining issues* ($p = 0.036$). *Research institutions from Switzerland* were associated with achieving *Reference* ($p = 0.035$) and *International NGOs/extension agencies* with achieving *Effort* ($p = 0.036$).

4.2.3. Knowledge users

Academic actors were the dominant knowledge users (this option was selected by 85.1% of the respondents). They published project results in scientific articles, created training materials, disseminated the knowledge to students, and used results for medical teaching material and for access to equipment and training. It is worth noting, however, that academic actors used the knowledge not only in publications (i.e. *Transmission/communication*), but also in *Application/replication* when co-creating new knowledge. Governmental institutions were in second place (71.3%), using the knowledge to e.g. develop policies, institute processes, initiate actions, or adjust plans. In third place were local communities (58.5%), who made use of tools and trainings, considered sustainable development options, adopted recommendations, and applied technologies developed by r4d research projects. Those who used the knowledge least were private sector actors (12.8%) and vulnerable groups (8.5%) such as women's groups. At the global level, there was a strong presence of scientists as key users; at the local level, communities and local governance actors were the dominant users; and at the national level, the most important knowledge users were universities, governments, and NGOs.

4.2.4. Effects on the societal areas of science, policy, and practice

Quotes on the effects of the utilization of research knowledge on *Practice* concerned for instance community and organizational transformations e.g., "*community actors' improvement of local environmental awareness*", or "*new organizational forms for collective saving and investments*". Fig. 3 shows that the strongest rating of effects of knowledge utilization was for science, both regarding *new insights* and *developing/testing new tools and methods*. With regard to influencing policies, we found "medium effects" (stated by 25.4% of the respondents), with explanations such as influencing agendas, but weak (32.5%) or no effects (45.7%) on actual changes in regulations. Regarding "strong effects" (32.7%), there was a gap from science to policy changes (where only 10% of the respondents saw "strong effects") and practice (15.5%). However, 57% also stated that it was too early to assess the full impact of research knowledge on policies. Interestingly, policies were strongly influenced by building trust ($p = 0.036$) and by the involvement of all five steps from Fig. 1($p = 0.003$).

4.3. Project processes

4.3.1. Transdisciplinary project process

In terms of steps implemented in their project (Figs. 1), 53.2% of respondents selected the first step, *Participatory problem definition*. Nearly 52% selected *Integration of natural and social sciences* and an overwhelming majority – 81.8% – said they had implemented *Integration of non-academic actors and their knowledge*. Just over half of the respondents implemented *Social learning process* (53.2%) and *Collective action for implementation* (52.1%). Just under half (47.1%) selected four or even all five steps in their projects, while 18.6% selected none or only one of them. When asked about TD, 57% considered that they applied a transdisciplinary approach, 14% did so partially, 14% did not apply TD, and 2% did not know. Respondents who indicated that their project was transdisciplinary also indicated having more stages in their research project ($p = 0.035$); a breakdown of these respondents showed that a

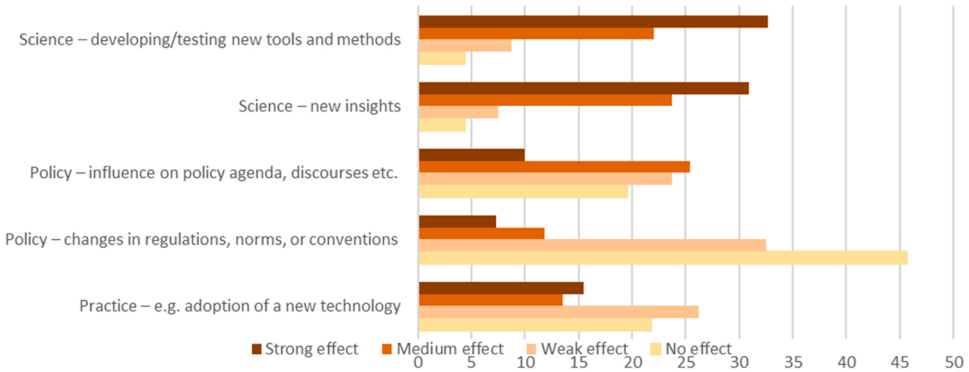

Fig. 3. Effects from the utilization of knowledge on the societal areas of science, policy, and practice as indicated by respondents (in %).

majority reached all 10 stages. Respondents who indicated that their project used a TD approach reported on average 8 ± 3 stages, and those who indicated no TD approach reported on average 6 ± 2.8 stages. These results indicate that projects using a TD approach reached more stages. However, an understanding of TD referring to the involvement of non-academic actors in research was not even across the sample. Only for 16% of the qualitative responses, TD involved non-academic actors in the research process, while 61% of respondents described "transdisciplinarity" as a collaboration between different academic disciplines. In only 6% of the cases, respondents describe TD as participation of non-academic actors in decision-making, e.g. "*co-design of the project from the beginning with different stakeholders*". We also coded the answers into three types of knowledge, namely systems knowledge, target knowledge, and transformation knowledge (Hirsch Hadorn et al., 2006; Hirsch Hadorn et al., 2008). Producing systems knowledge was the most frequently mentioned, by 67.5% of the respondents. Target knowledge was indicated by 15.6%, and transformation knowledge by 48.1%, as e.g., "*Community participation in selecting and practising sustainable land management options*". Usually, systems knowledge and transformation knowledge were mentioned together, while target knowledge was the least mentioned.

4.3.2. When and how non-academic actors participated in the co-creation of knowledge

Involvement of non-academic actors was stronger after securing funding than when designing the project. After securing funding was also the project phase where most changes (as a result of stakeholder involvement) in the projects happened, mostly in terms of methods. Non-academic actors were most strongly involved in validating results towards the end of the projects (33%). The second strongest involvement (28.8%) was as advisors in more than one role. The role in which non-academic actors were involved in a project also had an influence on knowledge utilization: We observed that for *Social learning,* non-academic actors needed to have a role "as researchers" ($p = 0.037$) to achieve this stage of knowledge utilization. The *Influence* stage was significantly related to non-academic actors as *Sources of information* ($p = 0.026$), *Representatives* ($p = 0.024$), and *Advisors* ($p = 0.045$). The qualitative answers indicated that gathering the knowledge of the actors and their voices opened possibilities for non-academic representation and influence: *"*[*we conducted*] *workshops and forums to design aspects of research,* e.g., *a workshop on conceptualizing productivity with unions"*. As a consequence, effects became more likely because the projects included the knowledge that directly affected the partners and the potential beneficiaries, and they may also have played a role in decision-making: *"Smallholder farmers and microenterprises using our technologies were involved in research and in the improvements of the technologies*", or "*groups of people (formers rebels, former military members) could interact for a better reconciliation"*.

4.4. Contextual factors influencing the utilization of research knowledge

Many projects took place in challenging contexts with environmental problems, restrictive societal norms, or political instability. Infrastructure and the political situation were most frequently mentioned as the most strongly influencing contextual variables (both positively and negatively). Furthermore, there were limitations of infrastructure (both of communication and of public use). Bureaucracy and corruption among government officials were also often mentioned as limiting factors for the utilization of research knowledge, e.g., "*The biggest variable in our case is the political environment which has made it difficult to conduct research and engage in participatory activities without putting participants in danger*". Also, the quick turnover of politicians in charge was a problem: "*Changes in officials at the ministry level were also major obstacles in the implementation of the national study and the source of long delays. Commitments were made with previous officials and the new ones in place did not necessarily follow up with those commitments*". Further, societal norms could be a strong obstacle, e.g., "*Intolerance and 'machismo' are often hindering talents, or even participation*". Gender was often mentioned as a "*real issue"*, but not explicitly dealt with in most projects.

4.5. Results validation

The workshop confirmed the main findings, e.g. the relatively low impact on changes in policies at the time the survey was administered, which the participants attributed to longer process of societal transformations. The workshop also helped to clarify that the projects actually used transdisciplinary approaches by including non-academic actors in their processes, but that this involvement was not strongly based on theory. This might be an explanation of the results presented in Section 4.3.1, (1) that the understanding of TD was often conceptually reduced to interdisciplinary collaboration, and (2) that target knowledge was the least mentioned form of knowledge. The workshop participants emphasized that involvement towards the end of a project, or only in the validation of project results, should not be considered transdisciplinarity. They also stressed the role of researchers in knowledge utilization – "*we share results, but we also share process*" – and that a rather artificial separation is often made between doing transdisciplinary science and sustainability transformations. The question arose whether it is mainly the research results that cause observed changes, or also the actors involved, including the scientists.

5. Discussion

5.1. Assessing the guiding hypothesis

Our results indicate that there is indeed a relationship between transformations towards sustainable development and a transdisciplinary project process in our sample of 43 out of 54 Swiss r4d projects. This relationship is made possible through the integration of different forms of knowledge represented by different actors, both academic and non-academic. Since we understood sustainability transformation *as a structural change involving alterations of worldviews, values, agency, power relations, social networks, ecosystems, and physical infrastructure* (Schneider et al., 2019a,2019b), such a transformation can only occur when there is a reflection on researchers' roles and power relations that influence co-creation as well as the utilization of research knowledge in a process of empowerment (Rosendahl et al., 2015; Clark et al., 2016; Schmidt and Pröpper, 2017; Marshall et al., 2018). *Empowerment* in our sample was related to project activities and actors at the local level (4.2.2). Focusing more on these key actors may therefore contribute to sustainability transformations related to research knowledge.

5.2. Interpretation of the main results

Our results underline that classic dissemination of research knowledge alone is not enough to secure its utilization, let alone sustainability transformations. *Transmission/communication* and *Cognition* were the most mentioned stages of knowledge utilization, indicating that (1) other stages may need more time to become detectable; and (2) projects may be selecting this specific pathway (i.e., first focusing on conveying their knowledge through *Transmission/communication*, then aiming for *Cognition*, and then other stages). The predominant focus on *Transmission/communication* has mixed aspects: projects may remain on a basic level of sustainability transformation but allow for the co-creation of innovative solutions. So while *Transmission/communication* is necessary, it is not sufficient to achieve transformation, because it does not necessarily involve a reaction. However, a linear concept of bringing knowledge into practice has been acknowledged as still deeply rooted in understandings of science as well as policymaking (Kerkhoff and Lebel, 2006; Nagy et al., 2020), and it is possible that it was an underlying factor for the respondents of our survey. This may help to explain our

results, as during our analysis, we also got the impression that many respondents had answered the questions from a rather traditional, linear perspective.

Most stages of knowledge utilization had a better chance of being achieved when non-academic actors were involved. Only *Transmission/communication*, *Reference*, and *Effort* did not show this relationship. We were able to identify key groups that had many significant relationships with the stages of knowledge utilization, namely: Local NGOs and/or extension agencies, local private enterprises, local communities, and national research institutions (Fig. 2). While these should be more considered and empowered in future projects to secure the impact of research knowledge, there were other groups of actors (specifically vulnerable groups, indigenous groups, educational and governmental institutions) that had no significant link with any of the stages. Strategies need to be developed for involving vulnerable groups more in research for development activities. Marshall et al. (2018) drew similar conclusions from a TD process that emphasized subaltern knowledge in a peri-urban area in India. The process led to a systemic understanding of a cholera outbreak, an understanding which was in contrast to the dominant narrative of blaming individuals or disadvantaged groups. The TD process described by these authors was connected to a broader mobilization of the urban poor, which eventually led to better sanitation conditions.

In the cases we studied, non-academic actors were most strongly involved towards the end of the projects. Where they were involved earlier, it was often as advisors rather than decision-makers. This may be a disadvantage for co-creation and utilization of knowledge: Chambers et al. (2021) concluded that a lack of early co-creation may restrict the range of possible solutions. Similarly, Hegger and Dieperink (2015) found that only a minority of researchers in transdisciplinary projects really collaborated frequently with actors from policy and practice. We also found that stages important for transformation such as *Social learning*, *Influence*, *Empowerment*, *Building Trust*, and not least *Application/replication* were more likely to be reached when specific non-academic actors were involved in different roles (see Section 4.2.2). Hence, future projects should consider an early, diverse, and consequential involvement of such actors (Polk, 2015; Binder et al., 2020). Only involving non-academic actors as advisors or towards the end of project processes may result in these actors becoming mere recipients of information rather than co-creators of knowledge (Nagy et al., 2020).

We found strong ties from science to policy influence, but there was a gap from science to actual changes in policy and adoption in practice (see Section 4.2.4). Hoffmann et al. (2019) explicitly investigated the "project-to-science-and-practice-at-large-gap", and argue that this gap can be bridged by means of formal and informal interactions and linkage mechanisms between science and practice, enhancing knowledge utilization in both fields.

In our case, it was still early to know what or how strong the projects' influence really was. Sustainability transformation is a larger societal process (Brand, 2016). Project length was an often mentioned issue, both in the survey and in the results validation workshop. To tackle the identified science–policy–application gap, we recommend rethinking what future projects need in order to achieve the utilization of the co-created knowledge at more scales. Besides the early involvement of stakeholders and a more explicit inclusion of vulnerable groups, measures could include more flexible project processes that allow for an adaptive project structure, and the empowerment of non-academic partners in participation and decision-making not only in the projects, but also in the selection and conceptualization of the topics they deal with (Lang et al., 2012; Polk, 2015). Development projects sometimes have longer funding periods than research projects, which can be regarded as a strategic investment decision (Eschen et al., 2021). Therefore, TD to close this gap could be better developed and explored in longer research for development projects.

In most cases, the projects produced systems knowledge (empirical knowledge, Fig. 1, steps 2 + 3) and transformation knowledge together (Fig. 1, steps 4 + 5). Target knowledge (Fig. 1, steps 1 and 4) was the weakest of the three forms of knowledge. Not clearly defining target knowledge in and by the r4d projects may have been a weakness in this respect, given that defining the normative goals is crucial to successful solution-oriented transdisciplinary research for sustainable development (Lang et al., 2012; Mitchell et al., 2015). Only a minority of projects worked with all three forms of knowledge.

5.3. The importance of joint processes

A declared aim of the Swiss r4d program is to support policymaking towards sustainable development. Our results indicate that *Social learning* in particular supports policymaking, meaning that it is not enough to create e.g. policy briefs, but that such outputs should be accompanied by a process involving social interaction. Furthermore, the assumption that knowledge is transferred and disseminated to actors who have a knowledge gap is increasingly contested for ignoring social processes and a lack of efficiency, as described by Nagy et al. (2020). Rethinking this relationship by including power and interests in the considerations may make engagement with policymakers work better for sustainability transformations. A joint process of scientists and policymakers is as important as with other non-academic actors in sustainability-oriented TD research (Levesque et al., 2019). The question of how to foster co-creation among people who disagree or are not interested may be tackled by an existing societal demand with which projects can work. Non-academic actors should have a recognition in science, but co-creation of knowledge is often difficult to combine with "research realities" (Schmidt and Pröpper, 2017; Beran et al., 2021).

Research projects do not always achieve an early and equal involvement of non-academic actors; nor do they always aim for it. Often a difficult negotiation process, incorporating transdisciplinarity into classical research approaches adds openness – and thus uncertainty – to projects. In our study, we detected a clear phase of reorientation in the projects after funding was secured. This was manifested through adjustments in the research questions, methods, and allocation of funds. We regard the openness to such adaptations as an important feature allowing for coherent and empowering TD processes.

5.4. Limitations of the study and further research needs

Our study has some limitations: Although we provided definitions of the stages of the utilization of research knowledge and how we understood "sustainability transformation", we saw during the analysis of the data that the understanding of "transdisciplinary research" was inconsistent among the respondents, many of whom described it as a collaboration of different scientific disciplines. Furthermore, the surveys were only conducted in English, which may have prevented us from identifying other relevant perspectives. The analysis based on individual answers implies that we cannot directly compare the Swiss r4d projects and their outcomes to each other in this study. Furthermore, the result that transmission of research knowledge was the most achieved stage, while the empowerment of actors was the least achieved stage, seems to indicate a prevailing linear understanding of how the knowledge generated in the projects reaches society. At present, we are unable to say whether this was a reflection of the respondents' understanding of how the knowledge from their projects was used, or if this really represented the projects. Although all projects considered in the sample included the participation of academic and non-academic actors, we found several barriers for an equally wide participation of non-academic actors as respondents to the survey. Also, it may have been early for some respondents to have sufficient clarity about the projects' impacts.

The re-interpretation of an established analytical framework for research utilization proved useful for integrating more answers, for instance by taking *Transmission* also as communication from and in different directions, or by adding more reciprocal aspects, e.g., *Building trust*. In addition to the question of how to effectively involve

marginalized and vulnerable actors in r4d processes, further research should focus on mechanisms that increase research knowledge utilization for policymaking and behavioral change. Our validation workshop brought up the point that researchers tend to underestimate their roles as actors of change (see Hoffmann et al., 2019). It is therefore necessary to further explore the roles of academic and non-academic actors alike. Building on Pohl et al. (2010) and the "engaged researcher" debate (Duncan et al., 2019; Horton, 2019; Balvanera et al., 2020), engaged researchers' roles reach beyond facilitating co-creation of research knowledge and obtaining information, for instance by reframing and helping to redistribute *agency* of different actors in transdisciplinary research (Marshall et al., 2018; Chambers et al., 2021).

6. Conclusions

As engaged scientists concerned with sustainable development, our aim is for society to use research knowledge in evidence-based contributions for systemic solutions. To ensure utilization of research results it is necessary – but clearly not sufficient – to achieve the stages of *Transmission/communication* and *Effort*. Our analysis of the utilization of research knowledge in r4d projects identified some major trends and lessons learned, which can serve as the basis for further discussion and inform project planning and implementation. The findings on project processes related to knowledge utilization are important for research fields with TD at their core, especially transformative sustainability sciences.

Research for development projects that work with TD reach many and high levels of knowledge utilization and co-create different forms of knowledge that enhance sustainability transformations. The involvement of non-academic actors and their knowledge is not only beneficial; it is indispensable for sustainability transformations that are reflective and based on evidence. The earlier in the project the involvement takes place, and the more diverse the roles of the involved non-academic actors are, the more coherent the relevance, credibility, and legitimacy of scientific research for sustainable development. While this has been argued before, the present study, based on a relatively large sample of projects, provides evidence for this claim.

Author statement

The study presents our own original work and has not been published or submitted elsewhere. Prior to submission, the co-authors agreed on the present version of the manuscript.

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.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.envsci.2021.12.017.

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