



Conceptualising boundary work activities to enhance credible, salient and legitimate knowledge in sustainability transdisciplinary research projects

Lisa M. Andrews^{a,b,*}, Stefania Munaretto^a, Heleen L.P. Mees^b, Peter P.J. Driessen^b

^a KWR Water Research Institute, Groningenhaven 7, Nieuwegein 3433 PE, the Netherlands

^b Copernicus Institute of Sustainable Development, Utrecht University, Princetonlaan 8a, Utrecht 3584 CB, the Netherlands

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ABSTRACT

Transdisciplinary research (TDR) is one method where scientific and societal actors, each with various backgrounds, collaborate to address complex problems through knowledge co-creation. Despite its widespread use, TDR still lacks a common definition and methodology which makes it challenging to define clear mechanisms for knowledge co-creation that facilitate impact. Many authors across complementary bodies of literature provide lists of principles, best practices and approaches for TDR, but in practice these are rarely applied consistently. In this conceptual paper, we fill this gap and increase methodological coherence for sustainability TDR by consolidating these bodies of literature into a list of suggested activities for scientists and practitioners across contexts to apply to enhance the impact of their work. We consolidate primary and secondary literature from the fields of TDR, sustainability, research impact, stakeholder engagement, project management, boundary work and knowledge systems with our own practical experience in sustainability TDR projects. This synthesis leads to our conceptual and analytical framework of twelve boundary work activities that enhance credible, salient and legitimate (CSL) knowledge. Our assumption is that if boundary work activities are successfully implemented across the phases of a TDR project and enhance CSL knowledge, then there will be cascading effects that support a higher likelihood of knowledge use and outcomes that lead to impactful sustainability transformations.

1. Introduction

Sustainability problems are complex and oftentimes wicked (Mitchell, 2009; Rittel and Webber, 1973). They require many actors across backgrounds and disciplines to understand the nature of the problem, to collaborate, and to integrate knowledge to address the problem and enable change towards a more sustainable future (Apgar et al., 2009; Belcher and Halliwell, 2021; Pohl, 2005; Preiser et al., 2018). Transdisciplinary research (TDR) is one method adopted for tackling complex sustainability challenges, where scientific and societal actors from various backgrounds collaborate to address such complex problems through knowledge co-creation (Munaretto, 2021; Schneider et al., 2019; Walter et al., 2007). However, TDR lacks a clear definition and methodology which makes it challenging to define clear mechanisms for knowledge co-creation that lead to impact (Jahn et al., 2012; Lux et al., 2019). For knowledge to be used, it must be perceived as credible, salient and legitimate (CSL) (Cash et al., 2003; Kirchoff et al., 2013), and different activities are required to enhance knowledge use (Munaretto et al., 2022). Knowledge use may lead to different outcomes,

such as behaviour change, adoption of new technologies or new policies, all which may lead to impact over time (Belcher et al., 2020; Munaretto et al., 2022).

For our research, we understand TDR impact as the desired long-term changes agreed upon by the involved TDR actors based on the sustainability problem and scientific knowledge gaps they aim to address. In line with Belcher and Halliwell (2021) and the NWO (2018), these are changes in societal, economic and environmental states and flows towards sustainability transformations resulting from a chain of events to which TDR has entirely or in part contributed. For our research, this chain of events can be understood as the activities that support the co-creation and use of CSL knowledge across transdisciplinary boundaries, thus possibly resulting in changes in behaviour, practice or policies (research outcomes) that may lead to sustainability transformations (impact) (Belcher et al., 2020; Belcher and Halliwell, 2021; Lux et al., 2019; Schneider et al., 2019; Spaapen and Van Drooge, 2011). Accordingly, in this paper we will unpack the activities that support the co-creation and use of CSL knowledge across disciplines in TDR (Bracken et al., 2015; Brundiers et al., 2013; Hegger et al., 2012;

* Correspondence to: KWR, Groningenhaven 7, Nieuwegein 3433 PE, the Netherlands.

E-mail addresses: lisa.andrews@kwrwater.nl, l.m.andrews@uu.nl (L.M. Andrews).

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Hoffmann et al., 2017; Hoffmann et al., 2022), while remaining aware that scientific and societal actors interpret impact differently (Bornmann, 2013) based on their disciplines, backgrounds and cultures. Activities that enable interaction, learning, and knowledge co-creation across disciplinary boundaries and actors are referred to in the literature as boundary work (Akkerman and Bakker, 2011; Brundiers et al., 2013; Cash et al., 2003; Jahn et al., 2012; Lang et al., 2012). However, boundary work is seldom explicitly referenced in the TDR literature, nor is it allocated adequate time and attention in TDR in practice (Bergmann et al., 2021; Douthwaite and Hoffecker, 2017; Thompson et al., 2017).

Previous research has explored a number of TDR approaches (Brundiers et al., 2013; Hoffmann et al., 2022; Lang et al., 2012; Lux et al., 2019; Pohl and Hirsch Hadorn, 2007; Walter et al., 2007; Wiek et al., 2014) but has yet to explain how these enhance CSL as commonly recognised criteria for knowledge co-creation, as well as their use across boundaries that leads to impact. Some authors approximated this topic: for example, Hegger et al. (2012) conceptualised joint knowledge production success conditions via CSL knowledge as an assessment framework for climate change project processes, and Sarkki et al. (2015) explored how CSL influence processes and outputs in science policy interfaces. However, how and which boundary work activities enhance CSL knowledge in the domain of TDR and lead to impact has yet to be researched (Clark et al., 2016; Michaels, 2009; White et al., 2010). This gap leads to our conceptual approach for this paper, which seeks to harmonise the literature and practice on activities that enhance CSL knowledge as key criteria for supporting impact in sustainability related TDR.

This research addresses this gap by developing a conceptual and analytical framework to understand which boundary work activities are useful in TDR, and how they may enhance CSL knowledge co-creation (Cash et al., 2003; Lux et al., 2019; Pohl and Hirsch Hadorn, 2007; White et al., 2010). We focus our work in the domain of sustainability TDR projects. Our framework adds conceptual, analytical, and methodological clarity on how to organise and implement sustainability TDR projects that lead to impact, providing a shortlist of twelve boundary work activities distributed across TDR project phases.

In the following sections, we explain our methodology, define TDR projects, boundary work and our interpretation of boundaries. We then define impact delivery through the lens of CSL knowledge, followed by our illustration of TDR project phases. Thereafter, we introduce our conceptual and analytical framework which illustrates boundary work activities across TDR project phases and the proposed relationships for how they may enhance CSL knowledge. We end the paper with a discussion and conclusion.

2. Methodology

This conceptual paper provides an interdisciplinary perspective on TDR, exploring and connecting various disciplines and research fields with the aim to strengthen and integrate their key findings into a framework of boundary work activities for sustainability related TDR. This paper is based on an exploratory literature synthesis, building on primary and secondary literature, and on the authors' expertise and experience conducting and studying TDR projects. The first author has expertise in stakeholder engagement, facilitation and applying boundary work activities in international TDR project contexts, the second co-author has a water sector policy and governance and stakeholder engagement background and expertise, and the other two co-authors are from the field of environmental governance in academia. All authors have extensive experience in studying TDR projects from both universities and applied research institutes.

As a first step, we collected a broad range of interrelated bodies of primary literature within the domains of sustainability and impact, but also within the following fields: knowledge systems, TDR, stakeholder engagement, project management, complexity, research impact and boundary work. We used Google Scholar to search for literature, using (a

combination of) keywords including *complexity and sustainability*; *stakeholder engagement and impact and sustainability*; *knowledge co-creation and impact*; *transdisciplinary research and impact*. Within each of these keyword combinations, we first selected the 10 most-cited papers as a starting point. We then complemented this with secondary literature including practical guidelines, reports and manuals from funded TDR projects which were collected via snowballing on the primary literature and TDR projects related to the authors' work. The snowballing also led to identify additional primary literature. Our approach is exploratory (Jaakkola, 2020; Swedberg, 2020) in nature rather than a comprehensive literature review and therefore we did not follow a systematic literature review methodology. The first author conducted an exploration of the different bodies of literature based on inductive reasoning: first, synthesizing the literature in iterative waves, open coding using the Nvivo program to map and connect ideas, concepts and identify gaps between the interrelated bodies of literature, and snowballing on cited literature. The first author then translated the coding into a preliminary table of key factors that may lead to impact when involving multiple stakeholder types across disciplines in projects on complex sustainability topics. Following this, the first author then nuanced these factors by synthesizing ideas from literature on TDR and impact, followed by boundary work, knowledge systems and credibility, salience, and legitimacy. Next, through seven iterative brainstorming sessions ranging from one to two hours in duration between September 2022 and May 2023, all authors clustered the key factors into groups of boundary work activities that could enhance credibility, salience, and legitimacy across TDR project phases – with the phases identified based on a consolidation of the primary and secondary literature, as well as what the authors experienced in TDR projects in practice. The placement of the boundary work activities in phases was decided based on: 1) the three phases and principles from the 'Design principles for transdisciplinary research in sustainability science' framework of Lang et al. (2012); 2) the author's experience of how and when the activities are carried out in practice in a TDR project; and 3) based on their relevance in the different project phases. By narrowing down and filling in some gaps in Lang et al.'s (2012) framework, we came to a list of twelve boundary work activities. The selection of the boundary work activities was based on four criteria, namely whether the boundary work activities: 1) serve as "interface practices" (Lang et al., 2012); 2) build "a culture of productive and reliable collaboration" resulting in co-creation (Pohl and Hirsch Hadorn, 2007, p. 16) of CSL knowledge; 3) fill gaps that the authors have experienced in practice; and 4) are frequently mentioned in the literature. Finally, the authors conceptualised how each boundary work activity enhances CSL across different TDR project phases following the spheres of influence approach of Belcher et al. (2020), and provided examples based on literature and practice.

3. Impactful transdisciplinary research: co-creating knowledge through boundary work

TDR has evolved over the years as a useful research practice for tackling complex sustainability issues through knowledge co-creation between science and society (Jahn et al., 2012). For this research, we will use the definition of TDR as an "interface practice" (Lang et al., 2012, p. 27), whereby "transdisciplinarity is a reflexive, integrative, method driven scientific principle aiming at the solution or transition of societal problems and [...] related scientific problems by differentiating and integrating knowledge from various scientific and societal bodies [...]" (Lang et al., 2012, p. 26). For this paper, we focus on current societal problems linked to sustainability.

In practice, TDR can take on many forms and cover a range of topics (Lawrence et al., 2022) – from large-scale multinational and multimillion Euro research programmes (e.g., European Green Deal) on artificial intelligence, to national or local projects on public health. Furthermore, TDR involves different scientific and societal actors across disciplines, but also actors in distinct roles. How these actors co-create knowledge to

deliver impact is at the heart of TDR. We use the term knowledge co-creation to describe the activities of collaborating, sense-making, learning, and producing new knowledge among TDR actors (Munarretto et al., 2022).

Core knowledge co-creation activities described in the TDR literature include: collective problem framing (Bergmann et al., 2021; Hoffmann et al., 2022; Lang et al., 2012), designing knowledge synthesis and integration processes (Jahn et al., 2012; Munarretto et al., 2022; Pohl and Hirsch Hadorn, 2007), effective, inspiring and reflective leadership (Hegger and Dieperink, 2014; Hoffmann et al., 2022), translation of scientific knowledge into applied knowledge (Cash et al., 2003; Jahn et al., 2012) and building relationships between project actors while mitigating and mediating conflict (Cash et al., 2003; Hoffmann et al., 2022; Lang et al., 2012). These core activities harness process factors for successful knowledge co-creation, including mutual trust, transparency, respect, understanding and dual accountability (Belcher et al., 2020; Cash et al., 2003; Douthwaite and Hoffecker, 2017; Hegger and Dieperink, 2014; Mitchell et al., 1997; Reed et al., 2018). For example, Cash et al. (2003) observed in sustainability projects that if trust is lacking between actors due to reduced accountability or poor communications, ineffective knowledge co-creation occurred. In general, consistent application and terminology of core activities is lacking and these activities are often implicit in projects (Lawrence et al., 2022; Mollinga, 2010). We seek to unify these activities under the umbrella term of “boundary work.”

Sociologist Gieryn (1983) coined the term boundary work over 40 years ago by highlighting knowledge co-creation activities across the boundaries of science and society, despite these boundaries being fluid, flexible and ambiguous (Akkerman and Bakker, 2011). Boundary work has since been adopted by others in sustainability literature (Cash et al., 2003; Cash et al., 2002), natural resources management literature (Clark et al., 2016; Mollinga, 2010), and educational research (Akkerman and Bakker, 2011). Such literature illustrates boundary work through boundary crossing or interface activities such as mediation, learning, communication, negotiation, knowledge synthesis and translation (Akkerman and Bakker, 2011; Douthwaite and Hoffecker, 2017; Hoffmann et al., 2017; Hoffmann et al., 2022; Hubacek et al., 2006; Lang et al., 2012). For our research, we adopt the term “boundary work activities,” to encompass these core activities as creating the favorable conditions for crossing boundaries among disciplines, backgrounds and cultures in TDR projects.

In TDR literature, boundaries are generally defined between science and society with a research process that brings them together (Jahn et al., 2012; Lawrence et al., 2022). In this paper, we adopt a more nuanced understanding focusing on funded TDR projects and boundaries between the scientific and societal actors. Varied expectations, understandings, and knowledge disciplines confront each other in the boundaries between and among these different actors (D. Cash et al., 2002).

In the context of our unit of analysis (funded TDR projects), we articulate actors into four main groups based on their prevailing roles in a TDR project. First, we use the term ‘project partners’ to refer to the scientific and societal actors who receive funding to work on a TDR project. These typically include researchers, practitioners, civil society representatives, among others. In contrast, ‘external stakeholders’ are actors unpaid by the TDR project, consulted by project partners and who play a significant role in problem definition, co-creation and use of knowledge outputs. External stakeholders include scientific and/or societal actors, and are individuals or groups who can influence or be affected by the outcomes of a TDR project (Freeman, 1984). There may be overlap between external stakeholders and ‘end-users.’ ‘End-users’ are stakeholders who use the knowledge outputs of TDR projects during and after the project, although they may not be explicitly involved in the project itself. They often represent the intended target audience of the project’s outputs, and project partners may organise dissemination and capacity building activities aiming for specific outcomes such as

behaviour change or new policies. It is important to note that disciplinary boundaries exist within each of these three groups; for example, in the project partners group, there may be researchers from geochemistry and social sciences working together, and those boundaries need to be accounted for and crossed too (Akkerman and Bakker, 2011). A fourth group includes the ‘project funders,’ referring to national or international agencies, government bodies, or research organisations who fund TDR projects. The funders’ criteria for impact in a TDR project influence the scope and activities of TDR projects and often shape the problem definition (Rodríguez et al., 2013; Smits and Denis, 2014; Tetroe et al., 2008). ‘Third-party reviewers or facilitators’ exist outside the boundaries of a TDR project but provide support for boundary work or project evaluation as needed.

Collectively, we refer to these groups of actors as ‘project actors.’ Similar to Gieryn’s work (1983), we acknowledge that the boundaries across these actors are fluid and flexible. The crucial aspect of these distinctions lies in the awareness and performance of boundary work activities between and across the groupings to co-create CSL knowledge on the sustainability topic of the TDR project to enable impact. Different types of boundary work activities may be required across the different actors and at different moments in a TDR project.

4. Credible, salient, and legitimate knowledge in transdisciplinary research projects

Knowledge co-creation and use among project actors is complex (Belcher et al., 2020; Bornmann, 2013; Cash et al., 2003; Clark et al., 2016; Lux et al., 2019; Rushmer et al., 2019; Termeer and Dewulf, 2019; Walter et al., 2007). Impact usually manifests several years after project completion and it is difficult to determine causality (Belcher et al., 2020; Bornmann, 2013; Bozeman, 2003). Project actors may expect different forms and levels of impact: economic, social, environmental and/or scientific impact (Bornmann, 2013). We draw upon the work of Cash et al. (2003, p. 8086) who state that “scientific information is likely to be effective in influencing the evolution of social responses to public issues to the extent that the information is perceived by relevant stakeholders [as] credible, salient and legitimate” (see Table 1). Regardless of which impacts are expected, knowledge must be perceived through these three criteria to be used by stakeholders (Edelenbos et al., 2011; Klessova et al., 2020; Lux et al., 2019; Sarkki et al., 2015). This means that project actors need to balance expectations and perceptions of these criteria to co-create relevant knowledge through boundary work activities, increasing the likelihood of enabling a chain of events that may lead to impact.

Credibility, salience and legitimacy are synergistic, and enhancing one at the expense of another can lead to trade-offs (Cash et al., 2003; Cash et al., 2002; Hegger et al., 2012; White et al., 2010). For example, enhancing credibility over salience and legitimacy could lead to the involvement of only highly skilled experts, which could skew results with imbalanced perspectives. However, reaching consensus and balancing the three criteria in a timebound project is challenging (Clark et al., 2016; White et al., 2010). Project actors may strive for balancing

Table 1
Definitions of credibility, salience and legitimacy (CSL) used for this research.

Concept	Definition
Credibility	The perception that the knowledge co-creation process and knowledge co-created are of high scientific and technical adequacy and quality, based on sound evidence and arguments (Cash et al., 2003; Kirchhoff et al., 2013; Sarkki et al., 2015; Van Enst et al., 2014)
Salience	The perceived relevance and usability of the knowledge co-created for the specific stakeholders’ needs (Cash et al., 2003; Kirchhoff et al., 2013; Sarkki et al., 2015)
Legitimacy	The perception that the knowledge co-creation process was fair, transparent, and inclusive of all stakeholder views (Cash et al., 2003; Kirchhoff et al., 2013; Sarkki et al., 2015)

Table 2
TDR project phases.

Phase	Illustration
Design	In the design phase, project partners respond to a call for proposals, either from a funder or their own organisation. The initiating project partners iteratively identify other project partners and external stakeholders (Reed et al., 2009), draft the proposal, decide on roles and responsibilities, leadership (Hoffmann et al., 2022; Lang et al., 2012; Walter et al., 2007), budget, and submit the project proposal. Project partners narrow down the knowledge needs from the gaps identified in the call for proposal. This occurs through workshops and meetings, with multiple rounds of feedback from the funder culminating with the acceptance (or rejection) of the project. Project partners elaborate in the project proposal the objectives, goals, tasks, project architecture, knowledge co-creation methods, and monitoring and evaluation (Klessova et al., 2020; Lang et al., 2012; Lawrence et al., 2022; Norström et al., 2020; Walter et al., 2007). The purpose of this phase is to integrate problem framing and allow for knowledge co-creation in the implementation phase (Lang et al., 2012). One important caveat in this phase is that drafting project proposals is often unpaid, and therefore a balance needs to be found between ideal activities and timelines given limited resources and low likelihood of the project being funded
Implementation	The implementation phase starts when funding is awarded. Project partners implement project tasks via the objectives and goals and co-create knowledge outputs (Hoffmann et al., 2017; Hoffmann et al., 2022; Lang et al., 2012). Objectives, goals and tasks are refined and adapted as needed (Lang et al., 2012; Schneider et al., 2019). Project leaders sustain and enhance participation in the project, and continuously reflect, adapt and ensure the project's progress. Additional project partners are identified as needed. Project partners and funders check in and submit periodic progress reports. This phase includes knowledge dissemination and integration activities that intensify towards the end of the project and leads into the next phase
Post-project	The post-project phase occurs towards the end of the project and when the primary project funding has ended. The project funders (and any other actors as designed) evaluate the project (Lux et al., 2019; Walter et al., 2007). Project partners then reflect on the evaluation for future research and application. Project partners may host knowledge use activities depending on the type of funding scheme, in addition to planned post-project exploitation and dissemination activities (Lang et al., 2012; Lawrence et al., 2022). These are included to ensure the project's outputs are used in science and society beyond the end of the project or in future projects. Post-project activities are decided in the design phase and updated as needed in the implementation phase

all three criteria through boundary work activities – something that Hegger et al. (2012, p. 54) pointed out by illustrating that “knowledge production can be defined as a process in which the actors involved have managed to maximise synergy and minimise trade-offs between [CSL.]” This is aligned with previous research on knowledge co-production (Edelenbos et al., 2011) and boundary work, whereby ecologists – some of the earliest adopters of boundary work – argue that consensus is unnecessary for successful collaboration, but rather that co-created knowledge depends on reconciling, translating, negotiating and agreeing more or less on a mode of work (Star and Griesemer, 1989), accompanied by intentions to integrate knowledge (Edelenbos et al., 2011). Implementing boundary work activities operationalises such a mode of working together.

These three criteria do however come with limitations. For one, there is limited literature with practical advice for how to influence project actors' perceptions of knowledge (Sarkki et al., 2015) and project actors' perceptions may change over time (Cash and Belloy, 2020; White et al., 2010). Hence, Sarkki et al. (2015) argued to add ‘iterativity’ as a fourth criteria to better capture this dynamism. Project actors therefore must balance and understand the changing perceptions of CSL in sustainability TDR projects over time. Second, project actor groups also consist of different subgroups of scientific and societal actors with different perceptions of what is CSL. For example, certain groups of academic project partners may perceive credible knowledge based on predominant scientific norms, where other forms of knowledge such as traditional ecological knowledge are less accepted. Therefore, boundary work activities should be applied in ways that recognise these biases, and aim to overcome them with meaningful, intentional and inclusive processes to co-create CSL knowledge (Albert, 2014; Clark et al., 2016; Pereira, 2019).

5. Transdisciplinary research project phases

We have found that in TDR theory and practice, there tends to be three main project phases: the design, implementation and post-project phases – with certain boundary work activities occurring in each phase (Brundiers et al., 2013; Lang et al., 2012; Lawrence et al., 2022; Reed et al., 2009). Each phase and the overall sequence of activities are performed iteratively, with significant interdependencies and trade-offs among them (Brundiers et al., 2013; Lang et al., 2012; Lawrence et al., 2022). The literature suggests there is no clear analytical distinction between project phases, but for the purpose of this paper, such a distinction is useful to distinguish between the boundary work activities across the three phases and how they enhance CSL in and across phases. In Table 2, we illustrate TDR project phases.

6. Enhancing credible, salient and legitimate knowledge through boundary work activities

In this section, we present our conceptual and analytical framework which illustrates boundary work activities across TDR project phases and the proposed relationships for how they may enhance CSL knowledge. Our conceptual model in Fig. 1 is inspired by Theories of Change (ToC), specifically Belcher et al.'s (2020) outcome mapping and spheres of influence approach. We borrow from this approach because it highlights the non-linear flows and mechanisms between the project phases, boundary work activities, knowledge co-creation, use and impact. Outcome mapping argues that “the relative influence of any project or programme declines the further one moves from the project boundary” (Belcher et al., 2020, p. 4), which we think applies well to TDR projects in practice. This is because our assumption is that if boundary work activities are successfully implemented across the phases of a TDR project and enhance CSL knowledge, then there will be a chain of events that support a higher likelihood of knowledge use and outcomes that lead to impact.

In Fig. 1, the sphere of project control is where the three project phases take place – design, implementation and post-project. The post-project phase is partially placed outside of the sphere of project control because some post-project knowledge use activities conducted within the project may lead to changes in practices, behaviour and policies (outcomes) only if other actions beyond the control of the project are taken by the targeted knowledge users. For example, for a new tool developed within a project to be used, adjustments need to be made in the operations of the end-user's organisation. While these changes may be fostered by the creation of the new tool, they are beyond the control of the project itself. A pre-project box is also included in Fig. 1, which has yet to be described in our characterisation of project phases as the scope of this paper is the TDR project itself. The pre-project phase includes the design of a call for proposals by a funder, which significantly influences the design and implementation of a TDR project (Smits and Denis, 2014). A funder may employ boundary work activities to consult project actors about current research and societal knowledge gaps to design the call, hence why the box is partially included in the sphere of control. Yet ultimately the final design of the call is beyond the sphere of project control.

The sphere of project influence includes both knowledge use by intended end-users or other actors and how that knowledge use may translate into changes in behaviour, practice or policies (outcomes). Knowledge use is situated on the border of both spheres of control and influence because boundary work activities for knowledge use can be both funded and planned by the project but are also beyond the scope of

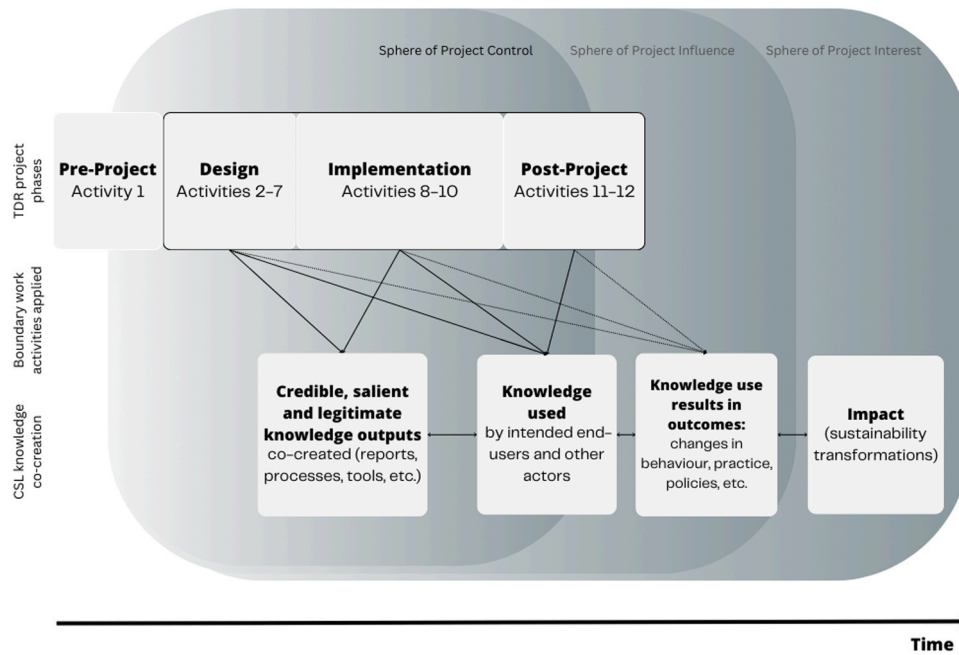


Fig. 1. Conceptual framework of boundary work activities enhancing credible, salient and legitimate knowledge in TDR projects inspired by Belcher et al.'s (2020) Theory of Change approach.

a project. For example, TDR projects may be designed with boundary work activities for knowledge use in the implementation and post-project phases, whereas other projects are designed to deliver only knowledge outputs without activities for knowledge use (Trouwloon et al., 2024). Furthermore, even with planning and boundary work activities, unexpected outcomes may occur as a result of knowledge co-creation, which may also positively or negatively affect the overall influence and impact of the project (Akkerman and Bakker, 2011; Douthwaite and Hoffecker, 2017). Therefore, the influence of the project declines in its ability to translate knowledge use into outcomes.

Finally, the sphere of project interest is where impact occurs. This domain is influenced by a myriad of variables, complexity and uncertainty; whether the knowledge actually leads to changes in behaviour depends not only on the perception of CSL, but also on external factors such as the political environment or the motivations of end-users. In sum, boundary work that occurs within the sphere of project control **directly** affects project actors' actions and leads to project outputs and some directly related outcomes (solid arrows). Other more long-term outcomes such as changes in practices, behaviour, and policies of potential knowledge users within the sphere of project influence are only **indirectly** affected by the project boundary work (dotted arrows). Typically, the interplay of project outputs and different types of outcomes leading to impact in the sphere of interest is only to a limited extent related to the project boundary work. We argue however that TDR projects can improve the likelihood of outcomes and impact by implementing boundary work activities across all project phases that are mindful of the project spheres (grey arrows).

In sub-Sections 6.1–6.4, we illustrate a list of twelve boundary work activities to be applied in practice across TDR project phases. This list is loosely based on the framework of Lang et al. (2012), where we have added examples of how each activity enhances CSL (see Table 3 for a detailed synthesis of how the boundary work activities enhance CSL). These activities were deduced as the most vital and interesting based on gaps and challenges in sustainability TDR knowledge and practice, as well as those most often cited in the literature. This is not a comprehensive list of all possible boundary work activities, but rather includes those that fit as “interface practices” (Lang et al., 2012) or boundary work, and build “a culture of productive and reliable collaboration”

resulting in knowledge co-creation (Pohl and Hirsch Hadorn, 2007, p. 16). The boundary work activities are listed across the TDR project phases for analytical purposes in this research paper, however, in practice they may be applied in a different order and many of them should overlap rather than be applied consecutively. For example, *Activity 8: Leaders coordinate and motivate* is listed in the implementation phase because it focuses on how they should lead; however, TDR project leaders should in fact be decided upon from the early pre-project or design stage, as noted in Activities 2 and 4.

This list can be used by all project actors as a set of suggested activities for how to organise boundary work in sustainability TDR projects. All project actors can refer to this list and attempt to implement boundary work activities to the best of their capacities, especially starting at the pre-project and design phases. However, many project actors may lack the skills necessary to implement such boundary work activities and may require additional support, learning and training to build competencies in this work (Akkerman and Bakker, 2011; Clark et al., 2016; Fortuin et al., 2023). As such, we envisage that such activities would be implemented by project actors who possess the skills to do so (integrators or boundary workers (Clark et al., 2016; Goodrich et al., 2020; Hoffmann et al., 2022) and/or those in leadership or project coordination positions from the initial phases (as referred to in Activity 2). As project actors witness, reflect on and participate in boundary work activities, they may also then begin to build competencies in such interface practices over time.

6.1. Pre-project boundary work activities

Activity 1: Co-create calls for project proposals

TDR project funders play a critical role in defining calls that contribute to solving complex sustainability challenges and deliver impact. Funders co-create calls for proposals with project actors (who may or may not submit proposals at a later stage) to identify the most relevant scientific and societal gaps these projects aim to solve, similar to the notion of agenda-setting (as argued by amongst others Clark et al., 2016 Schölvinck et al., 2020). This can be done through workshops, online forums and surveys and build on lessons learned from previous research. Co-creating calls for proposals with project actors provides

Table 3
Boundary work activities and proposed relationships for how they enhance credibility, salience and legitimacy.

	Boundary work activities	Credibility	Salience	Legitimacy
Pre-project	Activity 1: Co-create calls for project proposals with funders and stakeholders, that include knowledge gaps and societal problems informed by reflection on previous projects and context (Clark et al., 2016; Lux et al., 2019; Schölvinck et al., 2020)	Credibility is enhanced when scientific and societal actors perceive the design of the calls based on sound arguments and contextual knowledge and evidence proving the scientific and societal need for the research	Salience is enhanced when the project calls address societal problems and related knowledge gaps that are the most relevant to the stakeholders of a specific region or country in the existing socioeconomic, political, environmental context	Legitimacy is enhanced when the societal problems and related knowledge gaps are identified through unbiased, transparent, inclusive and iterative processes that ensure a collective understanding and framing of the problems to be included in the calls
Project phases	Design Activity 2: Iteratively identify all relevant project partners and external stakeholders to build a collaborative and inclusive team (Akkerman and Bakker, 2011; Bakhshi et al., 2016; Lang et al., 2012; Lawrence et al., 2022; Reed et al., 2009; Reed et al., 2018; Walter et al., 2007)	Credibility is enhanced when project partners and external stakeholders are perceived to be capable and experienced to conduct the research and address the societal problem identified. Gaps in expertise are iteratively identified and addressed	Salience is enhanced when the project partners and external stakeholders perceive the team as inclusive of all relevant partners and stakeholders based on the societal problems and related knowledge gaps and needs addressed in the specific context (Reed et al., 2018; Termeer and Dewulf, 2019)	Legitimacy is enhanced when the project partners and external stakeholders perceive the partners and stakeholder identification process as fair, transparent and unbiased (Reed et al., 2018; Walter et al., 2007) towards the different interests, motivations, values and beliefs
	Activity 3: Build relationships to ensure knowledge co-creation and mitigate conflicts (Cash et al., 2003; Clark et al., 2016; Lang et al., 2012; Walter et al., 2007)	Credibility is enhanced when project actors perceive each other as the most scientifically and societally relevant project actors and trust each others' expertise and competencies	Salience is enhanced when relationship building activities are perceived as relevant to support knowledge co-creation and translation, effectively reduce conflicts and enhance two-way accountability (Cash et al., 2002)	Legitimacy is enhanced when relationship building activities (formal or informal) (Clark et al., 2016) are accessible and open to all project partners and external stakeholders and are perceived as supporting knowledge co-creation in an inclusive and transparent manner
	Activity 4: Iteratively design a project architecture in which roles and responsibilities are fairly and explicitly defined based on skills, expertise and experience (De Jong et al., 2016; Hoffmann et al., 2017; Hoffmann et al., 2022; Lang et al., 2012; Walter et al., 2007)	Credibility is enhanced when the project architecture is perceived as matching identified roles with relevant skills, expertise and experience	Salience is enhanced when the project architecture is perceived as enabling team members' motivation, development and accountability, and avoiding tokenistic involvement of specific actors (De Jong et al., 2016; Lang et al., 2012)	Legitimacy is enhanced when the project architecture is perceived as transparent and unbiased, with awareness of conflicting roles and responsibilities, motivations and interests (Hoffmann et al., 2022). Agreement on rules of conduct and decision-making through transparent discussions enhances legitimacy and reduces conflict (Cash et al., 2003)
	Activity 5: Collectively define the scope of sustainability problem based on the identified societal problems in the project call for proposals and related knowledge needs (Hoffmann et al., 2017; Lang et al., 2012; Lawrence et al., 2022; Norström et al., 2020; Pohl and Hirsch Hadorn, 2007; Wiek et al., 2007)	Credibility is enhanced when the problem definition and related knowledge needs are perceived to be based on sound arguments and evidence from both science and society	Salience is enhanced when the project team works interactively with external stakeholders to define the societal problem and related knowledge needs that are scientifically and societally compelling and useful (Norström et al., 2020)	Legitimacy is enhanced when all project partners and external stakeholders are involved in the problem definition, feel heard and understood while discussing openly and transparently, resulting in an unbiased problem definition (Clark et al., 2016)
	Activity 6: Collectively design overarching project goal, activities, outputs, and outcomes , and make the relationships between them explicit (Belcher et al., 2020)	Credibility is enhanced when the project goals and activities are designed in a scientifically rigorous and logical manner including scientifically and societally relevant outputs and outcomes	Salience is enhanced when project goals and activities account for interests of all project partners and external stakeholders and are explicitly linked to scientifically and societally relevant outputs and outcomes (Belcher et al., 2020; Lang et al., 2012; Wiek et al., 2007)	Legitimacy is enhanced when all project partners are involved in an iterative, transparent and unbiased discussion and ideation of the project goals, activities and success criteria to achieve outputs and outcomes (Belcher et al., 2020)
	Activity 7: Collectively design progress monitoring structure which includes reflection moments to ensure effective and flexible implementation based on problem definition	Credibility is enhanced when the monitoring and reflection structure and implementation is perceived as scientifically and societally sound and facilitated by project partners or third parties with adequate skills in reflection and monitoring processes	Salience is enhanced when reflection moments are perceived as useful and relevant for advancing the project, with timely adjustments to maintain motivation and interest, delivering relevant goals, outputs and outcomes in light of changing circumstances	Legitimacy is enhanced when reflection moments are decided based on input from project partners and external stakeholders, and when all participate, feel heard and see their comments and ideas being taken into account
	Implementation Activity 8: Leaders coordinate and motivate (Hegger et al., 2012; Hoffmann et al., 2022)	Credibility is enhanced when leaders are deemed the most appropriate for the role by project partners and external stakeholders, based on their experience, skills and feedback	Salience is enhanced when leaders are perceived as accountable and coordinate in an effective, reflective, and flexible manner, and when leaders empower, inspire and recognise project actors' efforts and commitment (Hoffmann et al., 2022; Thompson et al., 2017)	Legitimacy is enhanced when leaders coordinate the project in a transparent, communicative, and unbiased manner with all project actors
	Activity 9: Co-create knowledge across disciplines and develop knowledge outputs (De Jong et al.,	Credibility is enhanced when project partners and external stakeholders communicate, learn, and	Salience is enhanced when there are continuous moments for updating and reflecting on the knowledge co-creation process to remain	Legitimacy is enhanced when all relevant project partners and external stakeholders are involved in knowledge co-creation through the development

(continued on next page)

Table 3 (continued)

Boundary work activities	Credibility	Salience	Legitimacy
2016; Edelenbos et al., 2011; Hoffmann et al., 2022; Lang et al., 2012)	understand each other to develop scientifically and societally high standard project outputs	relevant, flexible, and adaptive to changing societal and scientific situations within the scope of the project	and iteration of project outputs, and ensure transparent progress updates (White et al., 2010)
Activity 10: Generate and disseminate final targeted outputs (e.g. reports, methods, assessments, factsheets, tools, technologies, etc.) (Cash et al., 2003; Hegger and Dieperink, 2014; Hoffmann et al., 2022; Kirchhoff et al., 2013; Lang et al., 2012; Schneider et al., 2019)	Credibility is enhanced when final project outputs are tailored for each target audience based on sound evidence and arguments while upholding scientific integrity (Cash et al., 2003; Schneider et al., 2019)	Salience is enhanced when outputs are relevant and tailored to the language, knowledge needs and worldviews of all project partners, external stakeholders and intended end-users through iterative discussion (Hoffmann et al., 2022; Lang et al., 2012; Pohl and Hirsch Hadorn, 2007)	Legitimacy is enhanced when outputs are finalised and shared in transparent, equitable, and accessible way (Cash and Belloy, 2020; Lang et al., 2012) and are perceived to have incorporated feedback from all stakeholders in previous phases to ensure knowledge use
Post-project Activity 11: Inclusive and reflexive TDR project evaluation (Hegger et al., 2012; Klein, 2008; Lang et al., 2012; Lawrence et al., 2022; Lux et al., 2019)	Credibility is enhanced when project partners, external stakeholders and third parties (Lang et al., 2012) beyond the funders perceive the project evaluation as rigorous based on scientific and societal standards and feedback	Salience is enhanced when project partners and external stakeholders perceive the project evaluation as useful to reflect on the success of their TDR project, providing constructive criticism, revealing positive or negative externalities and opportunities for future research and practice	Legitimacy is enhanced when the evaluation is perceived as fair, honest and inclusive of all project partners, external stakeholders and third-party perspectives and accessible for reflection and future research
Activity 12: Integrate knowledge into science and society (e.g. trainings, workshops, communications, etc.) (Cash et al., 2003; Clark et al., 2016; Hegger and Dieperink, 2014; Hoffmann et al., 2022; Kirchhoff et al., 2013; Lang et al., 2012; Schneider et al., 2019)	Credibility is enhanced when knowledge integration actions are perceived as rigorous and scientifically and societally sound	Salience is enhanced when the knowledge integration actions are perceived as useful, timely and relevant by the intended end users, with contextual relevance for ensuring knowledge use	Legitimacy is enhanced when knowledge integration actions are perceived as inclusive and transparent, whereby all relevant intended end-users can provide feedback to shape and test the integrated products, to ensure knowledge use in an open and iterative manner best suited to the context

funders with input on how to support TDR projects and which monitoring and evaluation criteria are most suitable for the needs of the context (Lux et al., 2019) enhancing CSL of the project proposals, design and implementation.

6.2. Boundary work activities in the design phase

In the project design phase, six boundary work activities are emphasised for enhancing CSL to enable impact.

Activity 2: Build a collaborative and inclusive project team

In order to enhance CSL, initial project partners (usually researchers (Wiek et al., 2007)) need to identify as early as possible all relevant project partners, leaders, external stakeholders and intended end-users inclusively, transparently and iteratively, based on the context and knowledge gaps (Clark et al., 2016; Pohl and Hirsch Hadorn, 2007; Reed et al., 2009). Initial project partners identify, list stakeholders and balance the team members between competencies, expectations, interests and motivations (Lang et al., 2012; Lawrence et al., 2022; Reed et al., 2009; Reed et al., 2018), delineating expertise and enabling coexistence (Akkerman and Bakker, 2011) as well as ensure diversity in gender, background, economic status and ethnicity to represent different opinions and experiences (Cash and Belloy, 2020). This balancing also includes understanding who among the project partners possesses the skills and competencies for boundary work (Fortuin et al., 2023; Hoffmann et al., 2022) to support boundary work activities. As the project team grows, the initial and additional project partners collectively discuss and reconstruct the team composition, fill gaps to reduce biases, and ensure a sense of balanced roles and responsibilities across the team members, which enhances both credibility and legitimacy (Akkerman and Bakker, 2011; Clark et al., 2016; Reed et al., 2009). Collective decision-making of the project team promotes trust and relationship building early on, which is linked to the project architecture in Activity 4, as are crucial process factors associated with CSL. Existing relationships can facilitate collaboration, but substantial renewing and engagement of project partners forms an important precondition for TDR projects that ensures openness and diversity of actors, supporting the dynamic nature of sustainability challenges (e.g., Klessova et al., 2020). Clark et al. (2016) suggest that the selection of project partners may be more effectively managed by a mediator or negotiator rather than researchers.

Activity 3: Build relationships to ensure knowledge co-creation and mitigate conflicts

Project leaders and other project partners (to a certain extent) are responsible for relationship building in TDR projects, which is a critical process factor for enhancing CSL. Constructive relationships are vital for knowledge co-creation (Chua, 2002; Reed et al., 2018; Sequeira and Warner, 2007): Chua's (2002) paper on the influence of social interaction for knowledge creation in organisations articulates the importance of relationship building, trust, commitment and motivation among members of a group, and highlights that the strongest predictor of knowledge co-creation in organisations is the quality of relationships among members. This lends well to TDR projects where more time should be dedicated to relationship building, from the beginning in the design phase flowing into the implementation phase. Project leaders host informal and fun activities help project partners get to know each other, which supports trust building and motivation to collaborate and co-create with others. At the same time, relationship building reduces the potential for conflicts. Should conflicts arise, project partners appoint a designated project mediator who can address conflicts through timely, active, reflexive meetings, with transparent discussion forums, explicit and mediated negotiations, and rules of conduct (Cash et al., 2003; Lang et al., 2012). Building relationships and mediating conflict should occur throughout the project to ensure project actors feel safe, supported, trust each other and able to connect with other project partners to co-create CSL knowledge.

Activity 4: Iteratively design a project architecture

Developing a clear understanding of the links between project goals, activities and actors' roles and responsibilities is crucial for ensuring credible and legitimate workflows that lead to salient outputs. Project partners, led either by an initial phase project coordinator or mediator as suggested by Clark et al. (2016), openly and transparently discuss and allocate roles and responsibilities based on competencies, expertise and motivations within an architecture (diagram or chart) to better understand the "interdependencies between actors," competencies, desired roles, project goals, and activities (Hoffmann et al., 2022; Klessova et al., 2020, p. 291; Lang et al., 2012; Walter et al., 2007). Project partners can enhance CSL through such collective discussions and understanding of each project partners' skills and motivations aligned with the project activities and goals and outcomes. Project actors can take on roles beyond the "researcher" or "practitioner" and assume roles such as facilitators, mediators, integrators, boundary workers or leaders depending on their skills (Clark et al., 2016; Hegger et al., 2012; Hoffmann et al., 2022). Such additional boundary spanning roles are vital for sustainability TDR projects to support knowledge co-creation across the boundaries of project actors and across disciplines (Clark et al., 2016; Goodrich et al., 2020) As the project team is formed (Activity 2), project partners become acquainted with one another and understand each others' capacities and strengths, which builds relationships (Activity 3) and process factors that contribute to CSL knowledge. This activity is also where project leaders should be decided based on their core skills and competencies.

Activity 5: Collectively define the scope of sustainability problem

Problem framing is a crucial component of TDR projects. Openly discussing, negotiating, learning about and refining the problem definition and knowledge needs supports effective knowledge co-creation across the project actors (Clark et al., 2016; Lang et al., 2012; Lawrence et al., 2022; Pohl and Hirsch Hadorn, 2007; White et al., 2010). Based on the call for proposals and the specific context, project actors outline the most relevant knowledge needs to fill the identified gaps identified, enhancing credibility and salience (Pohl and Hirsch Hadorn, 2007; Star and Griesemer, 1989; Wiek et al., 2007). Project actors define a common language and understanding across disciplines to target the right problems with appropriate knowledge outputs, enhancing salience. Involving all stakeholders early on supports trust building and the overall legitimacy of the process (Reed et al., 2009). For example, Mollinga (2010) discusses how in a TDR land and water management project in Uzbekistan that a lack of sense-making and clear communications in the problem framing resulted in differences in understanding of the local meanings of water scarcity, and therefore reduced the relevance of the knowledge outputs for external stakeholders and end-users.

Activity 6: Collectively design overarching project goals, activities, outputs, outcomes

Collective design of the project goals, activities, outputs, and outcomes among project partners is crucial for ensuring coherent workflows and enabling impact. To enhance CSL, project actors iteratively shape the problem into a specific vision for the project, and then perform a back-casting exercise to design the project activities, outputs, and outcomes that build towards the desired societal and scientific impact (Pohl and Hirsch Hadorn, 2007). This boundary work activity is closely linked to the project architecture (Activity 4), as it defines "how the tasks are decomposed and coordinated [over time and it] contributes to the organisation of the collaboration and to the success of the project" (Klessova et al., 2020, p. 291). Project partners carefully discuss the project activities, knowledge outputs (e.g., reports, white papers, methodologies, etc.) and knowledge use activities (workshops, demonstration events, etc.) that translate into outcomes with external stakeholders and end-users (Clark et al., 2016). A Theory of Change (ToC) is a useful approach which visualises this process, helps define activities and assumptions, and track progress (Belcher and Claus, 2020). We recommend using a ToC as a project design tool, and also for the co-creation of the call for proposals.

Activity 7: Collectively design progress monitoring structure including reflection moments

Actively monitoring and reflecting on intermediate activities and results is often neglected despite it being cited in the literature as a crucial step for knowledge co-creation and use, as well as trust building and transparency (process factors for CSL) (Hoffmann et al., 2022; Horn et al., 2022; Lang et al., 2012; Schneider et al., 2019). Project partners enable moments of reflection and progress monitoring with other project actors to update and integrate knowledge and research results throughout the project (Lang et al., 2012; Pohl and Hirsch Hadorn, 2007). This also means checking in with the end-users and the contextual needs to ensure the project is delivering on the intended outputs and outcomes – continuously ensuring CSL. Reflection and progress monitoring includes looking into the goals and activities of the project, the project architecture and team compositions, and any other process or content areas in the project that require discussion and adjustments. If done successfully, project partners already plan periodic reflection moments in the design phase.

6.3. Boundary work activities in the implementation phase

In the project implementation phase, three boundary work activities are emphasised for enhancing CSL to enable impact.

Activity 8: Leaders coordinate and motivate

Leaders are accountable to all other project actors to ensure the project is progressing throughout the implementation as per the project goals (Activity 6) (Hoffmann, Weber, et al., 2022). Leaders also enhance "capabilities for and interest in participation [in the project through] setting and enforcing the boundary conditions for collaborative efforts" (Lang et al., 2012, p. 35) and sustaining those over time to ensure commitment (Brundiers et al., 2013; Hoffmann et al., 2022, p. 3; Thompson et al., 2017). Leadership is therefore a crucial boundary work activity that influences the success of a TDR project. Leaders take on roles as boundary managers (Cash et al., 2003) or integration experts (Hoffmann et al., 2022) and must be chosen carefully in the pre-project or design phases based on their skills, competencies, and expertise, and collectively by all project partners and external stakeholders in the design phase to enhance credibility. Leaders sustain commitment from the beginning of the project to the end through boundary work activities and others such as big picture thinking and recognising and celebrating successes (e.g., small wins) (Termeer and Dewulf, 2019). Project leaders also "ensure accessibility, schedule meeting times for maximum participation, and enable engaging and meaningful discussions where all project partners and stakeholders feel heard" (Lang et al., 2012, p. 35) enhancing salience and legitimacy. Leaders also take on varying levels in a TDR project, from the main project leader at a coordination level, to task leaders. We place this activity in the implementation phase because it is about how leaders sustain commitment and support knowledge co-creation across boundaries during the project; however, this should start from the design of the project.

Activity 9: Co-create knowledge across disciplines and develop knowledge outputs

Knowledge co-creation is at the heart of TDR projects and builds on the success of the implementation of the prior boundary work activities. Knowledge co-creation depends upon project actors' relationships and trust (Activity 3) and a shared problem definition (Activity 5). As per the project goals and activities (Activity 6) and project architecture (Activity 4), project leaders or facilitators host workshops, communities of practice (Wenger, 2011), living labs (Bulkeley et al., 2016) or meetings among project partners for early stage knowledge co-creation (Edelebos et al., 2011; Hegger et al., 2012; Hoffmann et al., 2022; Lang et al., 2012). Project actors co-create intermediary project knowledge outputs (e.g., reports, policy briefs, factsheets, methodologies, technologies, demonstration sites) together with the external stakeholders and end-users (Clark et al., 2016; Hoffmann et al., 2017; Hoffmann et al., 2022), which enhances legitimacy. Project outputs are decided on

collectively in the design phase based on what is most salient for the context. The challenge is for the knowledge outputs of the TDR project to remain relevant to all project actors in a changing environment (Cash and Belloy, 2020; Sarkki et al., 2015). For example, in a European project on climate change, we observed that the project activities and outputs decided upon in a local case study during the proposal writing phase required refinement once the project started to better serve the local needs. This arises because the project initiators usually make assumptions about different possible knowledge outputs without consulting the local end-users. Hence, sufficient flexibility is required to allow for unanticipated project outputs and is linked with Activity 7 on monitoring and reflection.

Activity 10: Generate and disseminate final targeted knowledge outputs

Generating and disseminating final targeted outputs of TDR projects may seem rather obvious, however to enhance CSL, it includes several rounds of feedback from other project actors and ensuring the knowledge is targeted to the different end-users (Lang et al., 2012, p. 34; Pohl and Hirsch Hadorn, 2008). The latter is done by translating the outputs into useful formats for the end-users and organising activities that support knowledge use and in some cases enabling outcomes (Fig. 1) (Pohl and Hirsch Hadorn, 2007). Exactly how to disseminate and target the knowledge outputs is decided iteratively in the design phase in Activities 4 through 7. Integration and dissemination activities include presenting results in workshops or trainings to targeted groups of end-users, possibly with the ambition of those end-users finding value in the outputs and fostering new behaviours, policies or technologies (Fig. 1). This depends on whether the end-users perceive the knowledge outputs as CSL. For example, if policymakers are an intended end-user, TDR project partners translate the results based on the perceptions and interests of the policymakers into policy briefs and follow political agendas for timeliness (Pohl and Hirsch Hadorn, 2007).

6.4. Boundary work activities in the post-project phase

In the post-project phase, two boundary work activities are emphasised for enhancing CSL to enable impact.

Activity 11: Inclusive and reflexive TDR project evaluation

“Reflexive approaches to [TDR] processes are outlined to systematically strengthen the potential for societal effectiveness” and are seen as a useful exercise for completed projects (Lux et al., 2019, p. 183). We argue that the evaluation of a TDR project should include project actors beyond the funders to enhance the CSL of the evaluation process and outcomes. Project partners, external stakeholders and end-users should then also collectively reflect on the success criteria agreed upon in the design phase (Activities 5 and 6) and whether or not they achieved those goals within the project context (De Jong et al., 2011; Lang et al., 2012), as well as any unintended consequences, achievements or challenges. This can be done during discussions, meetings or feedback forms on which type of transformations or actions the knowledge outputs triggered and the implications for future research and practice (Walter et al., 2007). Funders can request project partners to reflect on the evaluation results and provide comments and feedback on implications for future research – with time and budget allocated to do so. Once the evaluation and reflection are complete, funders should make them accessible and transform the lessons learned into targeted project briefs for other project actors to reflect and learn from previous research for future projects (Bozeman, 2003).

Activity 12: Integrate knowledge into science and society to deliver impact

This boundary work activity builds on Activity 10 and can be applied to translate project outputs into outcomes. We argue this activity should be included in TDR projects to lead to impact. Similar to Activity 9, this activity relies upon the success and perceived CSL of the TDR processes and knowledge outputs. Project partners may either design knowledge integration activities into the project, or have access to additional funding for workshops, trainings or hiring integration experts in the post-project phase or afterwards (Hoffmann et al., 2022). These

activities and integration experts build capacities for knowledge use and changes in behaviour, policies or technologies (Brundiers et al., 2013; Clark et al., 2016; Hoffmann et al., 2022). For example, in discussion with end-users, integration experts can determine which knowledge outputs should be integrated and how, therefore understanding what is most salient to these actors. Clark et al. (2016) noted in their study that co-creating tangible products with project actors (such as maps, drawings, models, and policy briefs, but also field trials and training materials) and gathering feedback helped projects enhance CSL and therefore knowledge use and outcomes. Funders should design specific criteria and allocate resources for such activities in the call for proposals, again connecting to the vital role of the funders and the need for co-creation and feedback as per Activity 1.

In Table 3, we give a detailed overview of possible relationships between the twelve boundary work activities and how they enhance CSL knowledge co-creation for each TDR project phase. This table provides an elaborate synthesis of possible relationships and not necessarily a complete overview or analysis of all possible relationships. This table is therefore meant to support TDR project actors in different roles and functions to reflect on how they implement boundary work activities and how to enhance CSL knowledge in doing so.

7. Discussion and conclusion

We developed a conceptual and analytical framework to understand which boundary work activities may be valuable in enhancing CSL knowledge co-creation and use that lead to impact in TDR projects. Our research combined key insights and concepts from different fields of literature and the authors’ experience working in sustainability TDR projects to identify a list of twelve boundary work activities across TDR project phases. We assume that applying these boundary work activities will foster knowledge co-creation that is deemed CSL and therefore used by the intended end-users (Cash et al., 2003), contributing to societal impact. This is a novel conceptualisation as, to the best of our knowledge, no other scholars have outlined potential relationships between this list of boundary work activities and how they enhance CSL as a proxy for leading to impact in TDR projects.

Our research is aligned with and builds on the work of other scholars who seek methodological coherence in TDR and other types of sustainability research and innovation projects (Klessova et al., 2020; Wiek et al., 2012) to deliver increased societal impact (Bauer et al., 2015; Hegger et al., 2012; Hoffmann et al., 2022; Kirchhoff et al., 2013; Lang et al., 2012; Pohl and Hirsch Hadorn, 2007). Building on Lang et al.’s (2012) framework and our experience with TDR, our conceptual and analytical framework adds two key considerations on boundary work in sustainability TDR – which have little reflection in literature and practice, with a few notable exceptions (see e.g., Dutch Research Council (NWO/NWA) routes by consortia approach¹). First, the importance of the pre-design and co-creation of the calls for proposals with the funders. We included one boundary work activity that recognises the critical role of funders and how calls for proposals should be co-created with project actors to ensure more appropriate, targeted, and flexible approaches. How funders draft the content and criteria in the calls for proposals, as well as the resources they provide to draft a project proposal all influence how projects are designed and implemented, which therefore influences the overall CSL of TDR projects. We therefore argue that there is a need to revisit how calls for proposals are designed and which criteria they include to ensure that other project actors have more flexibility, time, capacities, and resources to draft a TDR project proposal that is relevant to the stakeholders and therefore perceived as CSL from the beginning. Specific criteria and budget could be included in the calls for proposals that supports intentional reflection moments among the

¹ <https://www.nwo.nl/onderzoeksprogrammas/nationale-wetenschapsagenda/onderzoek-op-routes-door-consortia-orc>

project actors (Activities 7 and 11), as well as selection criteria for project leaders (Activities 2, 4 and 8), as these are crucial boundary work activities that can be linked to the design of the call for proposals. Despite reference to the important role of funders and evaluators in the literature (Douthwaite and Hoffecker, 2017; Lux et al., 2019; Schölvinck et al., 2020), there still remains little practical evidence for how to carry out this work. This boundary work activity would need to be conceptually unpacked and empirically assessed in practice to better understand and evaluate its influence over TDR projects.

Second, project actors often neglect post-project boundary work activities, which are crucial for ensuring knowledge outputs support outcomes and impact in practice. Although project actors aim for outcomes and impact in TDR projects, the specific activities for how to do so in practice are lacking, hence our inclusion of two post-project boundary work activities. Other interesting approaches that support knowledge integration into outcomes and impact include those from the Dutch NWO, who are exploring novel two-phase funding mechanisms.² The first phase focuses on developing knowledge outputs and ensure their use, and the second phase focuses on enabling outcomes. We link this again to the responsibility and accountability of funders for designing calls for proposals that enhance societal impact in TDR projects. With such funding mechanisms, this may provide the adequate budget, resources, planning, and commitment required by project actors to translate knowledge outputs into outcomes and impact (Activities 11–12). Traditionally once funding has ended, project partners have little desire to work on ‘old’ projects (Bauer et al., 2015) and pivot to new project ideas related to their own research agendas (Lawrence et al., 2022). Yet, funders who promote such flexible and phased funding mechanisms may foster more transparent and targeted research outputs and outcomes. Further studies are required to see which funding mechanisms or activities are most appropriate for generating impact beyond the sphere of project control.

We recognise that the identified boundary work activities may have limitations in practice, as a result of the complexity and uncertainty inherent in sustainability TDR projects, the time, budget, skills, competencies and personal disposition required to effectively implement such activities (Clark et al., 2016; Gulikers and Oonk, 2019; Hoffmann et al., 2022), as well as the power dynamics and politics among project partners, and the varied actions and tools to implement boundary work activities (Clark et al., 2016). Project actors can rarely plan for every eventual occurrence and therefore balancing the boundary work activities to enhance CSL over time should be adapted based on the changing context to embrace flexibility (Cash and Belloy, 2020; Clark et al., 2016). We recommend this list as a starting point for project actors to harness and sustain process factors, such as trust, transparency, and effective communications, which lead to CSL. This list of activities also supports the ongoing work and calls for training scientists and societal actors as ‘integration experts’, ‘boundary workers’, ‘brokers’ in transdisciplinary approaches (Brundiers et al., 2013; Hoffmann et al., 2022; Horn et al., 2022), building the skills and capacities for enabling knowledge co-creation and learning in TDR projects, and thus supporting the potential for impact (see e.g. the work of the ITD Alliance working groups³).

We also recognise that project boundaries are more nuanced than described in Section 3. Not only are there boundaries between the different types of project actors, but also between different types of knowledge and research disciplines within the identified boundaries (Clark et al., 2016). For example, Clark et al. (2016) identified boundaries between knowledge sources and users, new knowledge and established knowledge, and across the project actors. Another example

of nuanced boundaries comes from Akkerman and Bruining (2016) in the education literature, where they account for multilevel boundaries across personal, interpersonal, and institutional levels. However, for the purpose of this research, we decided to focus on the boundaries between the different TDR project actors, encompassing the different knowledge sources, backgrounds and motivations accompanying those actors. Therefore, the twelve boundary work activities listed in our research leave room for transcending the different boundaries inherent in actors, their disciplines, and their knowledge.

Finally, we would like to reflect on the methodology, and the exploratory and conceptual nature of this research. Exploratory and conceptual research can be considered different yet related approaches; exploratory research aims to study the unstudied, or to formulate new hypotheses about existing issues (Swedberg, 2020). Conceptual research “builds on theories and concepts that are developed and tested through empirical research” (Jaakkola, 2020, p. 19) and connects these in novel ways broadening the scope of current knowledge (Gilson and Goldberg, 2015). Both approaches aim to advance knowledge and yet, neither have commonly accepted guidelines, methods or research design, except for literature reviews and meta-analyses for conceptual papers (Jaakkola, 2020; Swedberg, 2020). As our paper aimed to explore novel connections among related concepts and develop preliminary propositions of potential relationships among them, our methodology took on a broad, exploratory, and conceptual nature, lacking perhaps in reproducibility. We selected concepts and ideas organically, based on identified gaps in the literature and our experience working in TDR in practice, while also structured along our research question – improving TDR project impact via boundary work activities that enable CSL knowledge. As discussed in the introduction, this is a novel way of organising the related concepts, resulting in our conceptual framework which explores relationships among those concepts. In this paper, we therefore sought to conceptualise and argue why these elements are connected, and how they may lead to a particular outcome (Cornelissen, 2017; Jaakkola, 2020) As such, future research should aim to systematically consolidate and test our conceptual and analytical framework in empirical studies. Additionally, future research should evaluate this set of boundary work activities in practice to identify and fill any gaps in boundary work activities across the phases of a TDR project, and across the other spheres of project influence and interest. It would also be interesting to research how CSL are perceived in sustainability TDR projects by different project actors, as well as comparing these insights across regions, contexts (Clark et al., 2016; White et al., 2010) and different types of sustainability projects. Novel research may also wish to build an evaluation structure for TDR around boundary work activities as processes with indicators for impact, building on the work of Belcher et al. (2020) and Walter et al. (2007).

Our research has the potential to support sustainability TDR projects across contexts, as well as other projects, programmes, organisations or companies with disciplinary or contextual boundaries that need to be crossed to enable CSL knowledge co-creation. In balancing the project actors’ perceptions of credibility, salience and legitimacy via boundary work activities across the TDR project phases – from defining the research scope, to implementation and knowledge integration – project actors can create the grounds for understanding, acceptance and relevance of the research results, which ultimately has the potential to influence behaviour, practice and policy. Given the urgency of the complex sustainability problems of our time, we require research to rethink how we design, implement, and evaluate TDR projects globally to ensure more effective knowledge use and impact (Kirchhoff et al., 2013).

CRediT authorship contribution statement

Lisa Andrews: Writing – review & editing, Writing – original draft, Visualization, Methodology, Investigation, Conceptualization. **Stefania Munaretto:** Writing – review & editing, Supervision, Methodology,

² <https://www.nwo.nl/en/researchprogrammes/dutch-research-agenda-nwa/thematic-programming/understanding-complex-pressures-wadden-sea-and-o-theams-action>

³ <https://itd-alliance.org/working-groups/integration-experts/>

Conceptualization. **Heleen L.P. Mees**: Writing – review & editing, Supervision, Methodology, Conceptualization. **Peter P.J. Driessen**: Writing – review & editing, Supervision, Methodology, Conceptualization.

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.

Data availability

No data was used for the research described in the article.

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