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ORIGINAL ARTICLE

The diversity of researchers' roles in sustainability science: the influence of project characteristics

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Abstract

Despite recent studies of researchers' roles in sustainability science, understanding the factors that influence them is a complex challenge. To address this lack of knowledge, we conducted a self-reflexive analysis involving 11 researchers from Rennes, France, who self-reflected on 12 projects conducted in north-western France over the past 15 years. This study investigates the roles of researchers in sustainability science projects by clustering these projects based on their characteristics and by evaluating the roles researchers assumed within each cluster. Four clusters were identified, ranging from academic research with minimal stakeholder involvement to highly interdisciplinary and transdisciplinary projects with significant stakeholder engagement. Researchers adopted multiple and dynamic roles, influenced by project characteristics but not deterministically. The role of transdisciplinary dialogue facilitator was frequently filled by intermediaries rather than researchers, highlighting a skills gap or a misalignment with traditional metrics of research performance. Self-reflection was significant in managing complex interdisciplinary and transdisciplinary projects, especially in clusters dealing with real-world problems and stakeholder interactions. The methodology, based on qualitative interviews and project clustering, proved effective and suggests that future research should include broader data collection and explore individual factors about mindset and motivation which influence researchers' roles. These findings emphasise the need for better support and recognition of diverse roles in academic evaluation and suggest the potential benefits of specialised intermediaries in transdisciplinary research.

Keywords Researchers' roles · Facilitation · Knowledge integration · Sustainability science · Transdisciplinary research · Interdisciplinary research

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Introduction

In response to pressing environmental issues, environmental researchers developed sustainability science, which became a distinct field after the ground-breaking article of Kates et al. (2001). They defined it as problem-focussed research that promotes interdisciplinary collaboration between social and natural sciences. It also emphasises communication between researchers and society, and thus is associated with a larger change in the way of doing science (Gibbons et al. 1994). Several authors have developed conceptual frameworks that emphasise the need for an iterative co-construction process that guides research and education (Brandt et al. 2013; Clark and Harley 2019; Lang et al. 2012; Wiek et al. 2011). Sustainability science also encourages transformations (Fang et al. 2018; Lang et al. 2012; Nagatsu et al. 2020).

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As indicated in project narratives and reviews, research in sustainability science faces multiple challenges, such as the necessary skills (Macher et al. 2021; Pohl and Hirsch-Hadorn 2008; Pohl et al. 2010; Steger et al. 2021), project management (Bark et al. 2016; Botha et al. 2014), stakeholder involvement and expectations (Macher et al. 2021; Renner et al. 2013), institutional support from funders (Hart et al. 2016; Macher et al. 2021), and differences between the objectives of science and those of society (Botha et al. 2014; Pohl et al. 2010). One critical issue is that researchers often assume multiple and unconventional roles in sustainability science (Arnold 2022; Bulten et al. 2021; Hilger et al. 2021; Macher et al. 2021; Miller 2013; Pohl et al. 2010; Wittmayer and Schäpke 2014). Roles in research can be classified as either knowledge-based or process/change-oriented (Miller 2013; Wittmayer and Schäpke 2014). Researchers must address major issues when adopting multiple and changing roles, such as the necessary skills (Muhar et al. 2013; Pohl et al. 2010; Wiek et al. 2011), research evaluation (Belcher et al. 2016; Durose et al. 2018; Steelman et al. 2021), and tensions between roles. These tensions arise between knowledge-based roles and socially engaged roles related to policy-making and real-world problems (Arnold 2022; Bulten et al. 2021; Hilger et al. 2021; Huning et al. 2021; Kruijf et al. 2022; Macher et al. 2021; Wittmayer and Schäpke 2014) and challenge researchers' independence and objectivity (Kruijf et al. 2022). These challenges stem from researchers' self-perceptions and expectations as well as the expectations and societal convictions about the knowledge of transdisciplinary partners (Bulten et al. 2021).

Despite recent studies of researchers' roles, understanding the factors that influence them is a complex challenge (Hilger et al. 2018; Horlings et al. 2020). Previous research has focussed on process steps, expectations, resources, and project organisation (Hilger et al. 2018), as well as personality traits, internal motivations, and gender (Carew and Wickson 2010; Miah et al. 2015), and scientific factors such as theoretical positionality, methods, and engagement (Horlings et al. 2020). Beyond those factors, we propose to explore how recent work on transdisciplinary research characterisation helps analysing roles. In other words, we focussed on project characteristics as a potential influence on researcher's roles. We explored key questions: do researchers adopt roles beyond conventional knowledge production? Do project characteristics influence researchers to assume unexpected roles? By linking roles analysis and projects characterisation, our research offers a novel insight into the factors which drive researchers roles in sustainability science. By improving the understanding of factors that influence researchers' roles, sustainability science researchers can better define their roles and meet their own expectations as well as the expectations of other stakeholders (e.g. policy makers, environmental managers, and citizens) involved in their projects.

To this end, we conducted a self-reflexive analysis involving 13 researchers in Rennes, in north-western France. Our study used Rennes as a case study due to its many research communities involved in environmental sciences, which include two universities (Rennes and Rennes 2), specialised higher education institutes (e.g. Institut Agro, EHESP) and national research organisations (e.g. CNRS and INRAE). Over the past 2 decades, collaboration has been encouraged between different fields of research and society, such as in scientific committees and research projects that are both inter- and transdisciplinary. As a result, researchers have re-evaluated their approaches and their responsibilities.

We first review research results of researchers' roles in sustainability science settings and then describe the projects used as case studies, the method used to describe the projects, and how we investigated researchers' roles. The results show similarities and differences among the projects, the activities that researchers performed, how these activities translated into roles, and whether the roles depended on project characteristics. We end by comparing the results to those of other studies, discussing implications of the results, and drawing conclusions.

Researchers' roles in sustainability science

Role theory

The concept of roles dates back to the 1930s (Mead 1934). Roles have been defined as expectations of a social group or category that define behaviour considered appropriate for and acceptable to group members (Anglin et al. 2022; Van der Horst 2016). According to role theory, people act in specific ways based on their social identity and current situation. The theory assumes that individuals have specific social roles and expectations for their own behaviour and the behaviour of others. Sociologists frequently use role theory to study concepts such as consensus, conformity, conflict, and role-taking (Biddle 1986). One important aspect of role theory is that it differentiates role-taking, which is based on clear and well-defined situations, from role making, which occurs in uncertain situations that have a variety of expectations (Hilger et al. 2018).

Researchers' roles

Researchers' roles include teaching, researching, managing, writing, and networking (Blaxter et al. 1998). Previous research suggested a distinction between researching, teaching, and administrative tasks and also described the role of gatekeeping (evaluating research) (Zuckerman and Merton 1972). More recent studies included up to six tasks:

networking, collaborating, managing, researching, publishing, and evaluating research (Kyvik 2013).

Researchers' roles in sustainability science

In sustainability science, researchers and stakeholders assume a variety of roles beyond those usually expected (Bulten et al. 2021; Macher et al. 2021; Pohl et al. 2010; Wittmayer and Schäpke 2014). A summary of researchers' roles in sustainability science is provided (Table 1).

Knowledge-based roles

The reflective scientist provides scientific expertise validated according to natural- or social-science norms. He–She also collects and analyses data from an observer's perspective without engaging in normative aspects (Pohl et al. 2010). This role is sometimes considered a "pure scientist" (Pielke 2007), "pure knowledge provider" (Macher et al. 2021), "knowledge provider" (Miller 2013) or "scientific analyst" (Hilger et al. 2021). This role, which is associated with a knowledge-first approach, is similar to traditional research. Another role associated with this approach is the expert, who advises policy makers and participates in committees as an independent knowledge provider or scientific advisor (Macher et al. 2021), also labelled as a science arbiter (Pielke 2007).

Policy-societal-based roles

Roles related to process/change-oriented approaches (Miller 2013) arise when researchers operate within the policy and/or societal space. In this case, they act as stakeholders or advocate for specific solutions (Parsons et al. 2017), but with science-led values, expectations, and interpretations. They are "issue advocates" (Pielke 2007). The literature also describes the role of change agent, who initiates learning and facilitation processes and helps addressing real-world problems (Wittmayer and Schäpke 2014).

These roles may include facilitating processes (Macher et al. 2021; Pohl et al. 2010; Wittmayer and Schäpke 2014). A facilitator can improve communication between thought collectives based on respect, openness, and deliberation (Pohl et al. 2010) or through mediating and empowerment (Hilger et al. 2021). The researcher helps the thought collectives achieve the challenges of knowledge co-production but does not directly engage in discussions. Knowledge integration role is performed by an intermediary or knowledge broker who understands the perspectives of different groups and helps find solutions that work for everyone (Wittmayer and Schäpke 2014). Both of these roles require active participation by researchers to mediate between different perspectives and provide critical reflection on sustainability issues (Wittmayer and Schäpke 2014). This typology has also been described by Kruijf et al. (2022). Self-reflexive scientists reflect on their positionality and normativity; they reflect

Table 1 Summary of the main roles described in the literature

Role	Description	Objective	References
Pure scientist	Focuses on generating new knowledge, maintaining objectivity and neutrality	Advance scientific understanding	Macher et al. (2021), Pielke (2007), Pohl et al. (2010)
Expert-science arbiter	Advises policy makers and participates in committees as an independent knowledge provider or scientific advisor	Support decision-making	Pielke (2007), Macher et al. (2021)
Knowledge broker-facilitator-intermediary-boundary worker	Facilitates the transfer and translation of scientific knowledge to policymakers and stakeholders Operates at the interface of science and policy, managing the boundary between the two domains	Bridge science and policy	Bulten et al. (2021), Pohl et al. (2010), Bednarek et al. (2018)
Issue advocate-change agent	Actively promotes specific policy outcomes based on scientific findings	Influence policy decisions	Pielke (2007), Macher et al. (2021), Parsons et al. (2017), Wittmayer and Schäpke (2014)
Self-reflexive scientists	Engage in self-reflection, self-reflect upon one's personal normative orientation and internal and external power dynamics, and raise/thematise roles and self-awareness	Reflect on norms, power, positionality	Wittmayer and Schäpke (2014), Hilger et al. (2021)

on internal and external power dynamics (Hilger et al. 2021; Wittmayer and Schäpke 2014).

Project management roles

Researchers also adopt the roles of coordinator (i.e. leads the process), choreographer (i.e. sets the stage and is responsible for interactions), communicator (i.e. responsible for communication), and result disseminator (i.e. disseminates results and raises awareness) (Hilger et al. 2021).

Tensions between roles

It can be challenging for researchers to assume multiple and varying roles because some roles may conflict or compete with each other, as many studies have highlighted (Bulten et al. 2021; Hilger et al. 2021; Huning et al. 2021; Kruijf et al. 2022; Wittmayer and Schäpke 2014). For example, knowledge-based roles could conflict with roles that involve policy-making and addressing real-world issues. One study noted tensions between scientific expertise and facilitation (Huning et al. 2021). These tensions can arise due to differences between researchers' perceptions and expectations and those of their partners in transdisciplinary projects. In addition, societal views of knowledge can contribute to tensions (Bulten et al. 2021). Some partners may expect researchers to do nothing but produce knowledge, while others may expect them to be activists (Scholz 2017) and facilitators of change. Lack of time can also be a source of tension, as facilitation and mediation can distract researchers from their knowledge-related role (Kruijf et al. 2022).

Factors that influence roles

Several factors influence the roles that researchers assume (Wittmayer and Schäpke 2014). They include ownership of the problem (or parts of it), the process, and its outcomes, which are a notion reflecting the intensity of stakeholder involvement. Other factors are the way sustainability is negotiated and defined; the way power between scientists and stakeholders is shared in the space for societal learning, and the kind of changes that are envisaged through the process. Engagement in different places, normative positions, theoretical choices, and research methods form the basis of an "embodied researcher" framework (Horlings et al. 2020). In one study (Hilger et al. 2018), real-world laboratories were analysed to determine how their conditions influenced researchers' roles. It found that process steps had little influence, but that researchers sometimes performed unexpected tasks due to conditions such as pressure to perform real-world actions, having a practice partner with limited resources, and working without a functional project group (Hilger et al. 2018). Another study that focussed on roles in research-industry partnerships related roles to a specific set of attitudes and behaviours (Miah et al. 2015) and highlighted the importance of the ability to communicate research to a range of audiences, and to understand and empathise with the industry. Factors that influenced the assumption of multiple roles included flexibility, project-management skills, the ability to challenge colleagues, and the ability to treat team members' views and values with respect (Miah et al. 2015). Another study highlighted factors related to skill sets, such as interpersonal skills that provided the ability to effectively work in a large team; a strong inclination to seek, value, and integrate a diverse range of perspectives; the ability to consider one's own values and negotiate shared values; experience in or openness to working across disciplines with stakeholders and in other contexts; and the ability to juggle and integrate a variety of knowledge, methods, and theories (Carew and Wickson 2010).

Materials and methods

Project database

We first created a database of projects by holding many group meetings from 2021 to 2022 in which eleven researchers (all co-authors except main author) presented one past or current project in which they had participated that aligned with principles of sustainability science. Researchers were early-career or experienced researchers with a history of inter- or transdisciplinary research on environmental subjects. During the presentations, we discussed multiple aspects of the projects, such as research questions, funding sources, participants, outputs, results, success factors, and difficulties encountered. One researcher (CC) described two projects. Consequently, the database included 12 projects (Table 2), all of which have been described in the peer-reviewed and/or grey literature (Appendix 1).

Individual interviews to characterise projects and identify researchers' roles

To characterise the projects and identity researchers' roles, individual interviews were performed by the lead author (one interview per project). Interviews were conducted face to face and their durations ranged from 1 to 2 h. They were not recorded; results were instantly reported in a spreadsheet.

Several papers have been published recently to identify research modes within transdisciplinary research (Jahn et al. 2022; Newig et al. 2019). In our analysis, questions were partially based on Jahn et al.'s protocol (2022). For the purpose of this study, we used the first part of the protocol, which consists of measuring the "real-world" orientation

Table 2 Details of the projects analysed

Project	Research question	Study sites	Participants		
			Scientists (disciplines—career stage)	Practitioners	Intermediaries?
Ecofriche	Analysing the effects of natural regeneration on wetlands	Aulne, Blavet, Léguer catchments-Brittany, France	Geography–ecology (mid-career)	Catchment managers, farmers	One-off
Eaux Cotentin	Investigating the factors that influence the water table in wetlands	Bessin and Cotentin wetlands-Normandy, France	Hydrogeology–ecology (mid-career)	Farmers	One-off
Sacadeau	Constructing a decision-making tool to assess the relations between pesticide transfer and farming practices	Fremeur catchment, Brittany, France	Digital sciences–agronomy (early career)	Catchment managers	–
Riskmanche	Analysing perceptions of health risks caused by water pollution	Coast of the English Channel, Brittany France	Microbiology–sociology (mid-career)	Recreational beach users and fishers	–
HZA	History of knowledge production about hedgerows	e Lter research site, Pleine Fougères, Brittany, France	Ecology–agronomy-laws (early career)	–	–
Gaetan	Investigations of buffer zones: biophysical functioning and social functions/relations between knowledge and action	Yar catchment, Brittany, France	Sociology–water–soil sciences (mid-career)	Catchment managers	–
Simfen	Developing an end-user-friendly hydrological service for hydrograph prediction in ungauged catchments	Brittany, France	Hydrology–data science (mid-career)	Catchment managers	Full-time
CPES	Implementing payment for ecosystem services to restore water quality	Lac au Duc catchment, Brittany, France	Geochemistry–agronomy–economics–sociology (advanced career)	Farmers, catchment managers	Full-time
Rivières 2070	Co-constructing, by integrating hydrogeological, social, and local knowledge, future landscapes under climate change	Lorient, Brittany, France	Hydrogeology–sociology (advanced career)	Catchment managers	Full-time
Parchemins	Narratives about farming in coastal areas	Douarnenez, Lezardrieux, Baie de la forêt, Baie de Lannion, Presqu'île de Rhuys, Brittany, France	Anthropology–agronomy–digital sciences–hydrology (mid-career)	Farmers	–
Eaux 2050	Water storage in aquifers under climate change	Arguenon, Valière, Yvel catchments, Brittany, France	Hydrogeology (mid-career)	Catchment managers, drinking water operators	Full-time
Diva	Agriculture and biodiversity-impacts-public policies	e Lter research site, Pleine Fougères, Brittany, France	Laws–ecology–geography (mid-career)	Farmers	–

of the research project; the "intensity of interaction" with actors from outside academia and the "type of practitioner contribution" (Table 4—Appendix 2 includes a full list of variables). We added a question aiming to measure the intensity of interdisciplinary interactions. Papers and reports from the research projects were also analysed to get additional information (Appendix 1).

Individual interviews were also used to investigate researchers' roles. To this end, we asked the following open-ended questions:

1. Can you describe your tasks and activities during the projects at different phases of the project?
2. Can you say whether one of these roles dominated the others? Would you rank the roles from the most important to the least important?

Following these interviews, activities described by the researchers were compared by the lead author with roles descriptions in the literature. Project clustering was done with R (R core team 2022); it is based on the k-means method (Lloyd 1982). Finally, the data on roles were compared with project clusters.

Results

Project clusters

The clustering process grouped the projects into four clusters:

- Cluster 1 contained two projects (*Eaux2050*, *Eaux Cotentin*); we name it "academic research". These projects involve a small number of stakeholders. Although stakeholders have identified a problem, they have not been directly involved in the research question definition. Moreover, they were not involved in the decision-making process. Instead, those projects were managed by researchers who relied on stakeholders' data. One project involved only one discipline, whereas the other project led to interactions between natural sciences (it did not involve social sciences).
- Cluster 2 contained four projects (*Ecofriche*, *Simfen, Rivières 2070*, and *CPES*) that were highly interdisciplinary and transdisciplinary. We name it "inter-transdisciplinary research". Projects integrated disciplines from the fields of natural/social sciences or numerical sciences/natural sciences. Stakeholders are major contributors to these projects. They have contributed to identify problems and define a research question. They provide data and are involved in the decision-making process.
- Cluster 3 contained five projects (HZA, *DIVA*, *Sacadeau, RiskManche*, and *GAETAN*) that were highly interdisciplinary and initiated by researchers. We name it "interdisciplinary academic research". Research questions were defined by researchers. Stakeholders were not directly involved in the decision-making process. Projects were interdisciplinary: they involved multiple disciplines; in some cases natural/social sciences; in other cases natural sciences/numerical sciences.
- Cluster 4 contained one project (*Parchemins*) that was locally contextualised, interdisciplinary, and initiated by researchers.

Researchers adopt multiple and changing roles

The researchers adopted six main roles in the projects: knowledge producer, expert, self-reflexive scientist, interdisciplinary dialogue facilitator, transdisciplinary dialogue facilitator, and knowledge integrator (Table 3).

The researchers assumed multiple roles that often changed over time (Fig. 1). In all projects except for *Eaux 2050*, researchers assumed multiple roles, with six projects requiring five roles and one project (*CPES*) requiring six. Researchers had three prominent roles: knowledge production, knowledge integration, and interdisciplinary dialogue facilitation, which overall were reported 11 times each. The role of knowledge production was the main role of researchers in five projects. The role of knowledge integration was also the main role in five projects. The role of interdisciplinary dialogue facilitation was the primary role in only one project. The role of transdisciplinary dialogue facilitation was endorsed by researchers in six of the projects and it was the main role in one project. Researchers were experts in six projects and self-reflexive scientists in seven projects. The role of expert was the main role in only one project. The role of self-reflexive scientists was never the main role.

Roles in projects' clusters

In "academic research" (cluster 1), researchers focussed mostly on knowledge production (Fig. 1). In one of the two projects, the role of knowledge producer was not the only one and included other roles (knowledge integration, interdisciplinary dialogue facilitation, transdisciplinary dialogue facilitation, and expert) although they were marginal.

In "inter-transdisciplinary research" (cluster 2), knowledge production was never the main role endorsed by researchers. Instead, roles related with facilitating processes were dominant (Fig. 1). The role of knowledge integration was the main role in three of four projects and is mentioned in all projects. As the projects were interdisciplinary, researchers have been interdisciplinary dialogue facilitators in all the projects. Transdisciplinary dialogue facilitation

Table 3 Researchers' roles and activities identified from individual interviews

Role	Activities/tasks	Similar roles in the literature	References
Knowledge producer	Design a research method to produce original knowledge, identify a research question, collect data, analyse results, conduct research (supervise doctoral students), present methods and results at conferences, and write articles for publication in journals	Reflective scientist Pure scientist Pure knowledge provider Knowledge provider Scientific analyst	Pohl et al. (2010), Pielke (2007), Macher et al. (2021), Miller (2013), Hilger et al. (2021)
Knowledge integrator	Integrate methods, data, and results from multiple disciplines and/or sources (including from practice and environmental management), and write and publish for interdisciplinary journals or conferences	Intermediary Knowledge broker	Pohl et al. (2010), Wittmayer and Schäpke (2014)
Transdisciplinary dialogue facilitator	Reconcile multiple views and interests from non-research partners, attend meetings with non-research partners, reformulate policy-making issues to co-construct research questions, present research to non-research audiences, work and iterate with multiple partners, coordinate work with multiple partners, identify the need for scientific support, attend meetings in which non-research partners share their concerns about environmental matters, share their policy-making/environmental management goals, identify their needs, and collect data from non-research partners	Similar to facilitator, although group members found it relevant to distinguish transdisciplinary dialogue facilitation	Pohl et al. (2010), Macher et al. (2021), Wittmayer and Schäpke (2014), Hilger et al. (2021)
Interdisciplinary dialogue facilitator	Reconcile multiple views and interests, including those from multiple disciplines, attend meetings to present work to researchers from other disciplines, communicate with researchers from other backgrounds, and co-construct research questions with researchers from other disciplines	Similar to facilitator, although group members found it relevant to distinguish interdisciplinary dialogue facilitation	Pohl et al. (2010), Macher et al. (2021), Wittmayer and Schäpke (2014), Hilger et al. (2021)
Expert	Provide answers based on existing knowledge to specific questions raised by policy makers and environmental managers	Similar to participating in committees and advising policy makers	Pielke (2007), Macher et al. (2021)
Self-reflexive scientist	Engage in self-reflection, self-reflect upon one's personal normative orientation and internal and external power dynamics, and raise/thematise roles and self-awareness	But some group members found it relevant to distinguish between self-reflection as defined by Hilger et al. (2021) and Wittmayer and Schäpke (2014) and the goal of producing self-reflexive knowledge	Hilger et al. (2021), Wittmayer and Schäpke (2014)

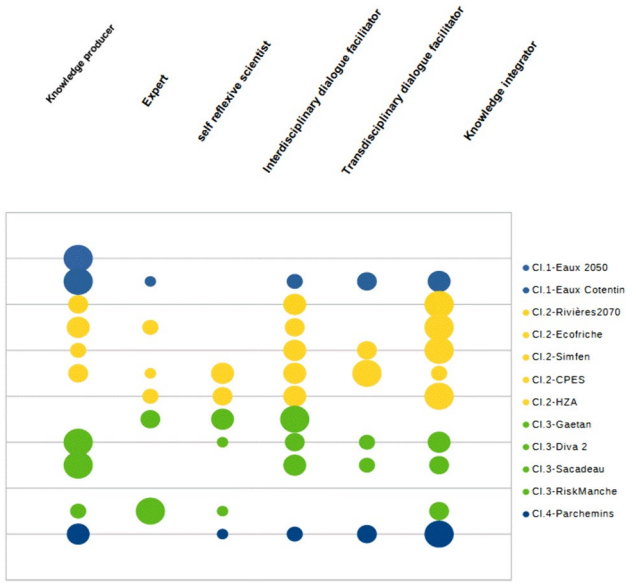

Fig. 1 Allocation of researchers' roles by project (row) and cluster (colour: cluster 1: dark blue; cluster 2: yellow; cluster 3: green; cluster 4: black). The diameter of circles is proportional to the role's rank in the project

was the primary role in one project (CPES); it was mentioned in two other projects. It is interesting to note that researchers did not take the role of transdisciplinary dialogue facilitator as a main role (except in CPES). This was explained in interviews by (i) the specific skills required to undertake this task (for seven researchers) and (ii) the influence of research evaluation which does not adequately measure transdisciplinary dialogue facilitation (for eight researchers in the group). Consequently, although they participated alongside stakeholders to transdisciplinary dialogue, they did not facilitate it. Specialists were hired to that end. The role of experts is mentioned twice. The role of self-reflexive scientists is mentioned in one project.

"Academic interdisciplinary research" (cluster 3) offered the most diverse range of roles (Fig. 1). While some projects were closer to cluster 1 projects regarding the roles researchers adopted, some projects were closer to cluster 2 projects. For example, in this cluster, regarding researchers' roles, some projects were closer to cluster 1 (Sacadeau, Diva) while some were closer to cluster 2 (GAETAN). However, a common feature of these projects is in the fact that cluster 3 included 4 of the projects that pushed researchers to be self-reflexive. Researchers pointed out tensions in those projects (Diva, RiskManche) between their academic goals and societal goals expressed by stakeholders, and also between disciplines. These tensions pushed them into self-reflection on power relationships, normativity and values.

The cluster 4 project is close to inter-transdisciplinary research with regards to roles. It relies on a broad range of knowledge and puts forwards the roles of knowledge integration and interdisciplinary dialogue facilitation.

Overall, project characteristics partially influenced researcher's roles. Knowledge production and its rank was clearly related to academic research (cluster 1). Knowledge integration and interdisciplinary dialogue facilitation (and their ranks) were related to "inter-transdisciplinary research" (cluster 2). However, this relation was partial, as projects in "academic interdisciplinary research" (cluster 3) had a range of roles.

Discussion

Projects clustering

Academic research (Eaux2050, Eaux Cotentin) seems to align with aspects of both Cluster 1 (purely academic research) and Cluster 2 (practice consultation) from Jahn et al.'s work (2022). While stakeholders are involved in identifying problems and providing data, they are not involved in decision-making. This resembles purely academic research's lack of practitioner involvement in decision-making but with a higher degree of stakeholder input in problem identification, akin to practice consultation characteristics.

Inter-transdisciplinary research (Ecofriche, Simfen, Rivières 2070, and CPES) shares similarities with Cluster 4 (ideal–typical transdisciplinary research) from Jahn et al.'s work (2022). These projects are highly interdisciplinary and transdisciplinary, involving stakeholders in problem identification, research question definition, and decision-making. This aligns with ideal–typical transdisciplinary research emphasis on significant interaction with practitioners and structured methods of knowledge integration.

Interdisciplinary academic research (HZA, DIVA, Sacadeau, RiskManche, and GAETAN) appears to have elements in common with both Cluster 2 (practice consultation) and Cluster 3 (selective practitioner involvement) from Jahn et al.'s work (2022). While stakeholders are not directly involved in decision-making, they play a role in identifying problems and providing data.

Cluster 4 (Parchemins) seems similar to some aspects of Cluster 4 (ideal–typical transdisciplinary research) from Jahn et al.'s work (2022). It is locally contextualised, and initiated by researchers, indicating a higher degree of academic control over the project's direction and decision-making processes.

Researchers adopt multiple and changing roles that are influenced by project characteristics

Sustainability science researchers assumed several roles throughout the research process, including knowledge

production, knowledge integration, facilitation, expertise, and self-reflection, which agrees with previous studies (Arnold 2022; Bulten et al. 2021; Hilger et al. 2021; Huning et al. 2021; Kruijf et al. 2022; Macher et al. 2021; Wittmayer and Schäpke 2014) showing that sustainability science researchers navigate between knowledge-based roles and facilitation roles. Most of the activities described by the group members corresponded to the roles described in the literature, although the group suggested some nuances for transdisciplinary dialogue facilitator and self-reflexive scientist. Group members distinguished interdisciplinary dialogue facilitation from transdisciplinary dialogue facilitation, arguing that the former is performed among researchers, whereas the latter involves non-research stakeholders. Lastly, group members did not assume the role of change agent, perhaps because most of the projects analysed were research projects, which although having some transformational aspects, were not like real-world laboratories or living labs, which can cause major changes in policy.

Project characteristics partially influenced the diversity of roles observed. Our results show some distinctive patterns as academic research allows researchers to focus on knowledge production, whereas research implying a higher degree of stakeholder involvement and interdisciplinarity causes researchers to adopt more roles, including facilitation roles and self-reflection. It also shows that this relation is not completely determined as in the interdisciplinary academic research cluster, roles allocation is in some projects similar to academic research while it is similar to inter-transdisciplinary research for other projects. From a methodological perspective, by combining methods aiming to identify research modes and roles analysis, our research goes a step further than previous studies that were based on the literature reviews (Hilger et al. 2021), analysis of real-world laboratories (Huning et al. 2021), and reviews of water-related knowledge-action projects (Bulten et al. 2021). Moreover, our study focuses on research characteristics (how is research conducted; how do stakeholders contribute). This is a complementary explanation to other factors pointed out in previous studies, such as process steps and conditions (Hilger et al. 2018), attitudes, behaviours or personality (Carew and Wikcson 2010; Miah et al. 2015); ownership of the problem, power relationships, how sustainability is negotiated and how change is envisaged (Wittmayer and Schäpke 2014).

The paradox of transdisciplinary dialogue facilitation

The observation that only one of the 10 projects that were transdisciplinary to some extent had transdisciplinary dialogue facilitation as the dominant role is a priori surprising. But the fact that researchers did not actively facilitate transdisciplinary dialogue does not mean that this role was not fulfilled. Instead, this role was endorsed by other actors. In certain projects in the sample, either the project manager (*Ecofriche*) or someone hired by him/her (*Rivières 2070*, *Eaux Cotentin*, *Simfen*, and *Eaux 2050*) worked specifically as an intermediary to improve dialogue between researchers and environmental managers. Seven researchers from our group pointed out that skills prevented them from assuming this role. This role requires specific skills, which can be challenging for researchers, who focus on knowledge production. Intermediaries are also called "boundary spanners", who work to bridge the gap between the worlds of science and decision-making by facilitating constructive dialogue between them and promoting the exchange of knowledge (Bednarek et al. 2018; Beechler et al. 2004; Delozier and Burbach 2021; Fischer 2015; Goodrich et al. 2020; Levina and Vaast 2005; MacGillivray 2006). Boundary spanners' skills include knowledge of a particular scientific field, communication, analysis, creative design, writing, policy, social science, and integration (Bednarek et al. 2018). Goodrich et al. (2020) emphasised the importance of providing comprehensive training for full-time boundary spanners and others who may occasionally perform boundary-spanning tasks.

The criteria by which researchers are evaluated is another factor that influences the latter not to assume the role of transdisciplinary dialogue facilitation (or not to make it the dominant role), for eight researchers from our group. Metrics such as the number of publications or citation indexes are used to evaluate research performance, but they capture only a researcher's influence and contributions as a knowledge producer (Belcher et al. 2016; Steelman et al. 2021). In sustainability science, researchers are expected to assume additional roles, such as spending time with stakeholders to co-produce knowledge. As the present study shows, these roles are essential and may even be the dominant roles in sustainability science research. Thus, the results of sustainability science projects differ from what researchers are used to producing, and research-performance metrics do not capture them easily (Steelman et al. 2021).

Self-reflection emerging in tense contexts

Self-reflection was a relatively important role in "interdisciplinary academic" research projects (cluster 3). Self-reflection, described as a "retreat option" and "complementary activity" (Hilger et al. 2018), is particularly useful in complex research projects that are both inter- and transdisciplinary in which tensions may arise (Horlings et al. 2020; Huning et al. 2021), such as between knowledge-based and facilitation-based roles and between researchers and practitioners due to different expectations (Aquilina et al. 2013; Bulten et al. 2021; Hilger et al. 2021; Kruijf et al. 2022). To resolve conflicts, project managers must meticulously

plan projects and clearly define and allocate roles among team members (Hessels et al. 2018). One reason reported by some of our researchers for the difference in self-reflection among clusters could have been the complexity of their settings. Most projects of Cluster 3 were initiated by researchers but addressed real-world problems and involved many stakeholders, which increased tensions between research and policy-making objectives and caused researchers to become more self-reflexive. In addition, it could be interesting to analyse whether specific disciplines and/or personality traits cause researchers to become more reflexive.

Limitations of the study and future research

The study's method enabled us to investigate researchers' roles and determine the influence of project characteristics on them based on a few projects. This method could be extended easily to a larger number of projects to assess the generality of these results. One limitation of the study was that we interviewed only one researcher per project who self-evaluated both project characteristics and his/her own role. Future studies could interview other researchers in each project, as well as their non-research partners, to attempt to obtain a more precise and extensive overview of researchers' roles. It would also be interesting to assess the influence of individual factors leading researchers to take one role or another. For instance, gender and internal motivations may affect the choice of researchers' role (Hilger et al. 2018). Personality is also considered as a potential driver of researchers' roles (Carew and Wickson 2010; Miah et al. 2015) that could be investigated in further studies, as well as disciplinary backgrounds and values. Specific inquiries could also be implemented for a better understanding of the transdisciplinary dialogue facilitation role or self-reflection.

Conclusions

The study aimed to categorise and analyse the roles of researchers in sustainability science projects by clustering these projects based on their characteristics and evaluating the roles researchers assumed within each cluster. The key findings and conclusions are as follows:

1. *Role flexibility and adaptability* Researchers in interdisciplinary and transdisciplinary projects should be prepared to take on multiple roles, which may evolve over time (Arnold 2022; Bulten et al. 2021; Hilger et al. 2021; Huning et al. 2021; Kruijf et al. 2022; Macher et al. 2021; Wittmayer and Schäpke 2014). Future projects should emphasise the importance of flexibility and adaptability among team members to effectively address the complexities of those projects.
2. *Importance of facilitation roles* Roles related to facilitating processes, such as knowledge integration and interdisciplinary dialogue facilitation, emerged as being dominant in certain clusters. Future projects should recognise the significance of these facilitation roles in promoting collaboration, communication, and the synthesis of diverse perspectives (Bammer et al. 2020; Cravens et al. 2022; Hoffmann et al. 2022). Our findings suggest in addition that effective transdisciplinary research may benefit from the involvement of specialised intermediaries to bridge gaps between scientific inquiry and practical application (Bednarek et al. 2018; Beechler et al. 2004; Delozier and Burbach 2021; Fischer 2015; Goodrich et al. 2020; Hoffmann et al. 2022). Despite the expectation for researchers in transdisciplinary projects to facilitate dialogue, this role was frequently outsourced to boundary spanners, highlighting a potential skill gap or a misalignment with traditional research performance metrics that prioritise knowledge production (Belcher et al. 2016; Steelman et al. 2021).
3. *Promotion of self-reflexivity* Self-reflexivity emerged as a key aspect in some projects, contributing to a deeper understanding of researchers' own assumptions, biases, and positionalities. Future projects should encourage and support self-reflexive practices among team members to mitigate potential tensions between knowledge-based roles and societal-policy-based roles (Bulten et al. 2021; Lang et al. 2012).
4. *Tailoring roles to project characteristics* While certain project characteristics partially influenced the roles that researchers assumed, there were exceptions and variations within clusters. Future projects should carefully consider their specific goals, contexts, and challenges when defining and assigning roles to researchers, rather than assuming a one-size-fits-all approach.
5. *Continuous reflection and evaluation* Reflective practices and ongoing evaluation of researcher roles and project dynamics are crucial for identifying strengths, weaknesses, and areas for improvement. Future projects should incorporate mechanisms for regular reflection and evaluation, allowing teams to adapt and refine their approaches based on feedback and lessons learned.
6. Beyond the scope of action of researchers, it is highly important that institutions provide adequate support. Recent research shows that there are many institutional obstacles for researchers willing to engage in interdisciplinary and/or transdisciplinary research. Institutional support should include appropriate training, specific evaluation and overall the way institutions shape research (Baptista et al. 2022; Cudennec et al. 2022; Hart et al. 2016).

By incorporating these conclusions into future interdisciplinary and transdisciplinary projects, researchers can enhance their ability to address complex challenges, generate innovative solutions, and contribute to meaningful societal impact.

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Appendix 2: Variables demarcating projects

We relied on an adapted version of Jahn et al.'s method (2021) to evaluate research modes within our project sample.

The groups of variables we took into account to characterise our project were about (see Table 4 for a complete list of variables that helped characterising research projects):

- real-world orientation;
- intensity of interactions with actors outside from academia;
- type of practitioner contribution.

Considering the small number of projects in our sample, in order to gain statistical robustness, we could not reproduce exhaustively Jahn et al.'s method. We excluded the following variables:

- variable 2 as answers were close to question 1 on research goals;
- variable 3 as all our projects included stakeholders. This variable could not demarcate any project.
- variables 4–7 as it did not seem straightforward to define what short, medium and long term meant. However, we kept question 8 (initiation) as it seemed to guide stakeholder involvement;
- variable 9 as no project involved stakeholders as principal investigators;

Table 4 List of variables to characterise projects

*ID/Name	Real-world orientation	Intensity of interactions with actors outside from academia			Type of practitioner contribution								
Question	'Relation between real-worldoriented and scholarly research questions.'	Did you explicitly apply methods of knowledge integration ?	Were the practitioners involved in the decision making within the project?	For this variable the number of different sectors that practitioner originate from is summated	Were persons from outside academia involved in your project, as initiator	To which of these areas did the practitioners in your project contribute. Definition of the problem	did the practitioners in your project contribute to define a research question ?	did the practitioners in your project contribute to knowledge production ?	did the practitioners in your project formulate needs and goals	did the practitioners in your project define norms and values ?	did the practitioners in your project defined conditions of change ?	did the practitioners in your project implement results of the project	how interdisciplinary is the project ?
Scores	score ranging from -2 to 2, from solely scholarly research question to solely real-world oriented research question	Binary [0;1]	Binary [0;1]	score ranging from 0 to 4, depending on the number of actors types involved	Binary [0;1]	Binary [0;1]	Binary [0;1]	Binary [0;1]	Binary [0;1]	Binary [0;1]	Binary [0;1]	Binary [0;1]	score ranging from 0 to 3 ; (one discipline : 0; two disciplines from the same field: 1; two disciplines from distinct fields, : 2; two disciplines with strong interactions :3).
Eaux 2050	-2	0	0	3	1	1	0	1	1	0	0	1	0
eaux cotentin	-2	0	0	2	0	1	0	1	1	0	0	1	1
ecofriche	1	1	1	4	1	1	1	1	1	1	1	1	2
Rivières 2070	0	1	1	4	1	1	1	1	1	1	1	1	3
simfen	1	1	1	4	1	1	1	1	1	1	1	1	2
cpes	1	0	1	4	1	1	1	1	1	1	1	1	3
sacadeau	-2	0	0	1	0	0	0	1	0	0	0	1	2
gaetan	-2	1	0	1	1	0	0	0	0	1	0	0	2
diva	-2	0	0	0	0	0	0	0	0	0	0	0	2
riskmanche	-1	0	0	1	1	0	0	0	0	0	0	0	2
hza	-2	1	0	0	0	0	0	0	0	0	0	0	2
parchemins	0	1	1	2	1	1	0	1	0	1	1	0	3

- variables 13–16 aiming to identify stakeholders involved in projects. Our sample was too small for that;
- variable 23; product development was irrelevant to our group. All projects involved scientists and decision makers, rather than industrial partners;
- variable 25–26 related to projects' follow-up as some projects are ongoing.

For the purpose of our analysis, the clustering process was done with the k-means methods (Lloyds 1982), via R. 4 clusters were identified, explaining 87.14% of the variance.

Author contributions GP wrote drafts of the article and performed the interviews. BB performed the principal component analysis. SD and VV helped analyse the results. CC improved earlier drafts. All the authors except GP presented projects, contributed to group meetings, attended individual interviews, helped analyse the results and reviewed several drafts of the article.

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Data availability The authors confirm that all data generated or analysed during this study are included in this published article.

Declarations

Conflict of 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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