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Published in:
Climate Services

DOI:
10.1016/j.cliser.2021.100282

Publication date:
2022

Document Version
Publisher's PDF, also known as Version of record

Climate Services 25 (2022) 100282

Contents lists available at ScienceDirect

Climate Services

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

Challenges and best-practices of co-creation: A qualitative interview study in the field of climate services

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ARTICLE INFO

Keywords:
Co-creation
Science-practice interface
Climate services
Boundary management

ABSTRACT

Climate services are becoming instrumental for providing actionable climate information to society. To understand the needs of society, climate service providers increasingly engage in processes of co-creation with practitioners. Yet, while these science-practice interactions are highly promising to match the demand and supply side of climate services, they come with challenges of their own. Potential barriers include difficulties in mutual understanding, diverging perspectives on the research problem, or a lack of resources and training in engaging with practice partners. Importantly, however, these barriers are surmountable if properly addressed. In this paper, we present the results of a series of interviews with researchers working in the funding line *European Research Area for Climate Services* (ERA4CS). We identify five challenges that these researchers are facing in their interactions with practice partners. From these challenges, we infer best practices that can help to strengthen such interactions. In line with other suggestions in the literature, we propose the role of a *boundary manager* as a promising way to put these best practices into action. This mediating role between science and society either can be taken by scientists themselves, or can be institutionalized as a dedicated position within climate service organizations. Adding to the experience that climate service providers already have, increased emphasis on boundary management could further improve their science-practice engagements

Practical Implications

In response to the complexity of climate adaptation, the co-creation of knowledge at the science-practice interface has become widespread in the field of climate services. Scholars of co-creation stress the importance of participatory and integrative modes of research for embedding climate science more closely into the contexts of knowledge use and application. In order to tailor climate projections, forecasts, vulnerability and risk assessments or other relevant climate information to the specific needs and contexts of end-users, climate service providers actively promote the joint production of knowledge. This implies to assess and negotiate persisting research gaps, user-needs and already available bodies of climate knowledge in close cooperation between policy-makers, climate scientists, business leaders, citizens and other stakeholders. The systematic inclusion of local, contextualized, and experiential resources of knowledge is therefore a key component for the co-creation of climate services.

In this paper, we address challenges that researchers are facing in the realm of co-creating climate services. Based on a qualitative interview study in the context of the funding line *European Research Area for Climate Services* (ERA4CS), we identify five challenges that regularly appear at the science-practice interface. The challenges of co-creation need to be addressed in the field of climate services and worked on in a constructive way to improve the relations between the partners. These challenges should be systematically taken into account by climate service providers, but also by policy-makers and funding organizations. By acknowledging that these challenges testify to new tasks and responsibilities for researchers, they should further incentivize and support capacity building in this realm. This is particularly important because in traditional disciplinary scientific training, practical engagements with societal actors and the inclusion of a wide range of knowledge are not yet part of the curriculum. A first challenge relates to the right timing for practice partner integration. While early and constant engagements are preferred by most

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https://doi.org/10.1016/j.cliser.2021.100282
Received 21 June 2021; Received in revised form 16 November 2021; Accepted 20 December 2021
Available online 22 December 2021

of our interviewees, choosing adequate entry points also depend on the state of the science and institutional conditions. Challenges can arise due to inappropriate funding conditions or a lack of motivation of practice partners to participate.

The importance of acquiring competencies in the field of co-creation leads to a second challenge. Whereas most of our respondents can rely upon some experiences in this domain, we also approached scientists who are rather new to this field. Furthermore, the number of conceptual frameworks, methods and practical tools for the joint production of climate services are continuously growing. It's a challenge in its own right to set up a consistent co-creation approach for a specific research context and being competent about its application as well as its theoretical and methodological underpinnings.

A third challenge arises due to the highly specialized languages and terminologies used in different practice domains and scientific disciplines. Finding common ground for meaningful conversations is a difficult task and takes time to accomplish. What's more, scientists tend to feel overstrained and distracted in cases of extensive correspondence with stakeholders. These tasks add up to other regular academic workflows, like data analysis, publishing or presenting research results. In situations where priorities between engagement practices and other tasks are not put in a reasonably balanced, trade-offs can arise.

A fourth challenge exemplified by our interview partners relates to the realities of stakeholders, who are exposed to complex real-word problems and often have to decide about adaptation measures in a timely and efficient manner. In this regard, scientists are required to understand the realities of stakeholders in order to improve the societal impact of climate knowledge. This is aggravated by the rather informal and implicit knowledge of professional practitioners, which becomes tangible only through intensified investigation.

The fair, equitable and transparent distribution of influence is another challenge to be acknowledged. Co-production always involves a degree of changing each other's perspectives through negotiations. Problematic situations can arise due to an uneven distribution of influence between different practice partners. A challenge for establishing a level playing ground is therefore to recognize disputes between actor groups at an early stage and to take them into account in the processes of co-creation.

As these challenges of co-creation regularly occur, they should be treated as productive thresholds to improve the quality of science-practice engagements. Therefore, we propose best practices that could guide researchers through their interactions with practice partners. A clear and realistic outline of project goals and potentials can motivate practice partners to get involved in projects of joint knowledge production in early stages. In order to acquire competencies, tandems of experienced scholars of co-creation with newcomers can help to facilitate learning. At the beginning of a project, providing enough time to clarify key concepts can foster mutual understanding between heterogeneous project partners. Furthermore, a comprehensive analysis of practitioners' contexts can help to integrate their needs into the project. Transparency and sufficient space to negotiate decision authority can help to balance influence in a fair manner.

In order to implement best-practices of co-creation, we propose the role of the boundary manager as a promising way to further improve science-practice engagements. This role can be taken by scientists themselves or by a dedicated position within climate service organizations. The essential characteristics of the boundary manager relates to the design and facilitation of productive boundary arrangements between science and practice. Activities include moderating between heterogeneous actor groups, translating and communicating scientific results for application in climate services and integrating different knowledge claims. In order to further strengthen co-creative research within climate service providers, policy-makers and funders should take considerable measures to support boundary managers. For example, the potential of this new role could be enhanced through capacity building initiatives. Climate service researchers need more opportunities to exchange experiences concerning science-practice engagements. Furthermore, there is a need for comparative reflections on different approaches, conceptual frameworks and methods being applied in climate service co-creation.

1. Introduction: Climate services and the challenge of co-creation

Due to the inherent complexities of climate change, successful climate adaptation requires a broad range of scientific and practical expertise. Even more importantly, it requires input on the needs and preferences that users of adaptation solutions have in their specific contexts, e.g. in agriculture, urban planning, or local administration. It is therefore widely acknowledged that collaboration between researchers and practitioners is key to deal with the risks of a changing climate (Buontempo et al., 2014; Vaughan and Dessai, 2014; Bremer et al., 2019). In response to the growing demand for user-specific climate knowledge, the field of climate services has emerged as a new and quickly evolving area of research (Bowyer et al., 2015; Street et al., 2015; Leal Filho and Jacob, 2020). Climate services bring together climate research and the practical application of results in an integrated approach. In order to do so, concepts of co-creation are increasingly adopted (Bremer and Meisch, 2017). Co-creation describes the inclusion of extra-scientific practitioners such as farmers, water managers or local citizens into research processes (Mauser et al., 2013). A central aim of co-creation is to produce societally relevant and practically usable products, while also ensuring the scientific quality of these products. Although the intensity of the exchange may vary between the different phases of co-creation (Mauser et al., 2013; Stauffacher et al., 2008), communication and mutual engagement of scientists and practitioners are crucial throughout the co-creation process.

However, while co-creation is most promising for matching climate services with user needs, these science-practice encounters are not trivial. As many experts in climate services have noticed (e.g. Lourenço et al., 2016; Jacobs and Street, 2020; Mwangu, 2020; Steuri et al., 2020), efforts must be taken to avoid mutual misunderstandings or mismatches between scientific and practical perceptions of climate change problems, e.g. regarding the temporal and spatial scales under consideration (Buontempo et al., 2014). Also, not all scientists are experienced with science-practice interactions, and resources for maintaining these relationships are often limited (Mauser et al., 2013; Jacobs and Street, 2020). Consequentially, it can be challenging to keep practice partners interested over the course of a research project. Yet, while these and other challenges have "been itemized with great clarity over the past several decades" (Jacobs and Street, 2020, p. 2), it has been noted that "there have been relatively few papers that suggest convincing solutions at scale" (ibid.).

Our objective in this paper is thus twofold: first, we aim to identify a set of challenges that researchers face when engaging with extra-scientific practitioners; second, we aim to derive a set of best practices and ways to implement them. The context of our research is the project *Normativity, Objectivity and Quality Assurance of Transdisciplinary Processes*, located at the *Climate Service Center Germany* (GERICS). The aim of this project is to identify best practices and evaluation criteria for co-creative research processes, particularly in the field of climate services. For this purpose, we present the results of twelve qualitative interviews with scientists working in the funding line *European Research Area for Climate Services* (ERA4CS). From these interviews, we derive five challenges of co-creation. We here confirm former findings regarding science-practice interactions, that are, however, somewhat scattered over the co-creation literature. At the same time, we argue that the challenges need not be perceived as necessarily problematic, but can be seen as indispensable yet exceedingly productive aspects of science-

practice interactions. Finally, we draw on a suggestion that Katherine Jacobs and Roger Street (2020) have recently made for the field of climate service, and that others have made before for sustainability science more general (Brundiers et al., 2013): the implementation of a *boundary manager* as a mediator between science and practice. This role, we argue, is a promising way to put best practices of co-creation into action. The focus on boundary management provides insights about how scientists actually enact, but also oppose and redefine emerging boundaries between science and practice. Challenges of co-creation occur in situations where boundaries between scientific and societal spheres become more fluid, permeable and open to mutual interferences. In these situations, the assumptions of co-creation can be made tangible. Going beyond existing suggestions in the literature, we argue that the role need not necessarily be realized as a dedicated position within a climate service organization. Alternatively, researchers can act as boundary managers themselves. Adding to the experience that climate service providers already have, increased emphasis on boundary management could thus further improve science-practice engagements.

2. Background and current state of research: Co-creation and challenges at the science-practice interface

According to a widely cited definition by the European Commission, climate services consist in "the transformation of climate-related data — together with other relevant information — into customized products such as projections, forecasts, information, trends, economic analysis, assessments (including technology assessment), counselling on best practices, development and evaluation of solutions and any other service in relation to climate that may be of use for the society at large" (Street et al., 2015). Since its advent about ten or fifteen years ago, the field has evolved rapidly, giving rise to a range of private and public service providers, research programs, academic institutions and expert networks (Cortekar et al., 2020; Stegmaier et al., 2020). Major initiatives include, inter alia, the *Global Framework for Climate Services* (Hewitt et al., 2012; Vaughan and Dessai, 2014), the *Copernicus Climate Change Service* in Europe, the international *Climate Services Partnership*, and a spectrum of national climate service institutes. In turn, the experiences gathered in these and other initiatives fostered a rich discussion about challenges and best practices in climate services (Lourenço et al., 2016; Wall et al., 2017; Vaughan et al., 2018; Jacob, 2020). For instance, Bremer et al. (2019) list seven desiderata of current day climate services: "(i) defining high quality climate services […], (ii) making climate services freely available […]; (iii) developing a market for climate services; (iv) increasing interaction between science providers and users; (v) improving the quality and communication of climate services for users' needs; (vi) increasing users' capacity to responsibly use climate services; and (vii) addressing legal, institutional and cultural barriers to using climate information" (ibid: 43). While the exact number and framing of challenges varies in the literature, this list gives a good impression of potential barriers in current climate services.

In this paper, however, we do not discuss the whole range of challenges that the climate service community is working on today; instead, we focus on a specific subset of challenges, namely those that arise when scientists and extra-scientific practitioners interact closely in joint research processes (i.e. number (iv) in the just mentioned list). In focusing on this particular type of challenges, we start from the observation that "[t]he literature seems to converge around the need to engage users in the coproduction of climate services in order to ensure that products are useful, useable, and used" (Vaughan et al. 2018, 383). However, while integrating users into climate service creation is broadly seen as crucial, the specific ways in which this is done are highly context dependent. This is one reason why there is no definitive canon of shared standards to determine the specifics of practitioner integration. Moreover, there is a variety of terms and concepts to describe such science-practice interactions (Vincent et al., 2018; Bremer et al., 2019; Daniels et al., 2020), including "transdisciplinarity" (Jahn et al., 2012), "team science" (Hall et al., 2018), 'integration and implementation science" (Bammer, 2013) and many others. In this paper, we will mostly use terms that have become popular in the climate service literature and in sustainability science more general: *Co-creation*, which refers to the entire process of practitioner integration, and the terms *co-design* and *co-production*, which refer to specific phases of co-creative processes (Mauser et al., 2013; Bremer and Meisch, 2017; Jagannathan et al., 2020).

Acknowledging that there is more than one possible definition of these terms (Bremer et al., 2019; Nagatsu, 2021), we here refer to a scheme proposed by Mauser et al. (2013). Developed as a conceptual framework for the research network *Future Earth*, this scheme distinguishes three consecutive stages of integrative sustainability research. The first step, co-design, is the joint effort of scientists and practitioners to define a research problem. This includes the identification and framing of a topic, its translation into manageable working packages, the securing of research funds, and the determination of responsibilities for the project partners (ibid: 428). The second step, co-production, concerns the joint creation of knowledge and other deliverables of the project. "During this phase integrated research is conducted as a continuous exchange among the participating scientists and with the stakeholders" (ibid). Most crucially, this phase requires ensuring both scientific quality and the practical relevance of the research. In the final stage, co-dissemination, the project's results are made available to a broader range of users. This includes aspects of comprehensibility and accessibility, but also a critical discussion on whether the results stand the test of practice (ibid). From here, new questions may emerge, leading to a new research cycle. The entirety of this process, i.e. the whole cycle from co-design to co-production to co-dissemination, is termed co-creation by Mauser and colleagues.

In the context of this paper, we concentrate on the first and second stage of co-creative research processes, co-design and co-production. We leave aside the dissemination of results and any activities in the aftermath of a project because our interview partners' projects had not been fully completed at the time of the interviews. The subsequent sections are thus dedicated to those challenges that may occur at the beginning and during the course of science-practice encounters in climate service.

3. Material and method: Problem-centered interviews with climate service scientists

As one of the leading funding lines in Europe in the field of climate services, the *European Research Area for Climate Services* (ERA4CS) is a suitable context to find out more about the challenges of co-creating climate services. Close collaboration between scientists and practice partners plays an important role in ERA4CS. The funding line's objective is to "improve user adoption of and satisfaction with CS [Climate Services]". ERA4CS aims to foster CS development "by supporting scientific research for developing better tools, methods and standards on how to produce, transfer, communicate and use reliable climate information to cope with current and future climate variability and change."[1] To achieve this, a robust understanding of user needs is considered as particularly important.

Between July and August 2020, we conducted interviews with researchers from 12 different ERA4CS projects. The projects cover different sectors, research domains and geographical scales, such as the aviation sector, land use patterns, or coastal systems. Within their respective projects, our interview partners have interacted with a broad spectrum of practitioners, ranging from public administration and civil society organizations to companies and citizens. Most of the projects

[1] ERA4CS Joint Call on Researching and Advancing Climate Services Development by (A) Advanced co-development with users, (B) Institutional integration,http://www.jpi-climate.eu/media/default.aspx/emma/org/https://doi.org/10869130/ERA4CS_joint+call_04march.pdf

have been active on local and regional scales and have therefore only occasionally engaged with actors on national levels. While all projects aim to support practitioners in adapting to climate change, different projects employ different methods of practitioner engagement (e.g. workshops or interviews). The kinds of produced services also vary among projects and include, e.g., tailored climate forecasts for specific sectors or decision-support tools for specific practical contexts.

The interview partners had different disciplinary backgrounds and varying levels of experience in the realm of co-creation, ranging from highly experienced co-creative researchers to researchers without any prior experience with co-creation. The scholarly backgrounds of scientists involved in this study reflect to some extent the development of the field of climate services and its interdisciplinary character. According to the origin of climate services in meteorology (Brasseur and Gallardo, 2016), five of our interviewees had a natural science background (meteorology, hydrology, physics). In recent years, also social scientists became more active in climate services and adaptation research (Bruno Soares and Buontempo, 2019; Skelton, 2021). This corresponds to three interviewees from the social sciences in our sample (cultural sociology, development studies). Another five interviewees had an interdisciplinary background (mostly environmental studies). In addition to their roles as traditional scientists, all interview partners also acted as "intermediaries" and "facilitators" (see sect. 6). That is, their activities included not only research, but also tasks such as facilitation, translation or mediation between different thought styles and interests within the project. Acknowledging that our data set is not representative for the entire field of climate services, we are confident that the diversity of our data helps to identify typical challenges that researchers encounter when engaging with practitioners in this field. Our sample thus comprises a broad spectrum of scientists from thematically different climate service projects, different levels of experience with co-creation, and different disciplinary backgrounds.

In order to collect our data, we conducted problem-centered interviews, an approach widely used in qualitative social inquiry. Its main characteristics are particularly useful to bring to light the subjective experiences, viewpoints, and perceptions of experts in relation to a clear-cut theme and problematic context (Witzel and Reiter, 2012; Döringer, 2020). Problem-centered interviews refer to relevant issues from the perspectives of interview partners, which are reconstructed and interpreted in a dialogic process during the interview. Contrary to quantitative social research, e.g. questionnaires with predefined answering options, a qualitative approach allows respondents to frame their experiences in their own words. It was thus essential to allow interview partners to freely formulate their thoughts and subjective experiences. Central principles of qualitative research such as openness, flexibility and an orientation towards the dialogic process of interviewing reflect these aspects (Flick, 2014). Following these principles, our interview guide did not serve as a rigid questionnaire, but rather as a structured orientation to include all important aspects of co-creation. We also encouraged our respondents to raise issues not covered by our questions. In order to stimulate the flow of conversation, we interposed spontaneous follow-up questions and short comments.

Our interview guide contained five broad themes, which ensured both the comparability and comprehensiveness of the empirical material. We initially posed questions about the context and aim of our interviewees' projects, as well as the general purpose of their practitioner engagement. We then proceeded with questions about the involved practitioners, e.g. how they have been identified and motivated, or what concerns they raised during the projects. In the third block, we addressed methods of practitioner engagement and our interviewees' experience with co-creation. The fourth section comprised questions about the influence of practitioners on scientific results and how the project dealt with competing knowledge claims. In the final part, we covered possibilities to improve practitioner engagement and learning effects between science and practice. The interviews lasted between 45 and 90 min and have been recorded and transcribed. To ensure anonymity, all information that could lead to personal identification have been changed or removed from the transcripts.

We developed our findings gradually on the basis of coding procedures suggested in *Grounded Theory* methodology (Charmaz, 2014; Corbin and Strauss, 2015) and used the software *MAXQDA* to manage and organize our empirical material. Investigator triangulation was applied by involving two investigators as interviewers and joint interpretation and analysis of empirical data within the research team. We also had the opportunity for an internal validation and discussion of preliminary findings. First results have been reviewed in September 2020 at a workshop organized by a working group dedicated to reflect upon co-creation in ERA4CS projects, where some of our respondents have been involved. Here, we received valuable feedback, which led us to reassess and specify our preliminary findings.

The first cut through the material enabled us to group interview quotes in relation to the most striking challenges of co-creation. We then refined our categories, merged and grouped some of them and split others into sub-categories. It was also important to continuously draw comparisons between interview statements to grasp differences and similarities in the material. During this process, five main challenges for the co-creation of climate services could be identified.

4. Results: Five challenges of co-creating climate services

In the following, we present challenges of interactions between scientists and extra-scientific practice partners in the field of co-creative research. Based on the analysis of our interviews, we identify five essential challenges, which have to be taken into account to enhance the quality of co-creation:

(1) Adequate entry-points and continuity of co-creation
(2) Competencies, skills and training
(3) Mutual understanding
(4) Integration of practitioners' realities
(5) Balancing influence

It will turn out that these challenges testify to specific tasks and responsibilities in the realm of co-creation that are typically not considered in traditional scientific training. We see challenges of different character and complexity (see Table 1). They mirror the perception of our interview partners.

4.1. Adequate entry points and continuity of co-creation

To co-create climate services, researchers have to make decisions about when and how interactions with extra-scientific practitioners should be carried out. Choosing adequate entry points for engagement is therefore one of the main challenges in the realm of co-creation. Early engagements, i.e. engagement at the beginning of the co-design phase of a project, are preferred by most of our respondents. In the following, an interviewee expresses her preference for cooperation even before a project gets funded:

> In the dream world, which doesn't happen very much in academia, it would be nice that we had designed the whole project together, even before it's funded. But that is rare. That's the dream situation (interview 1).

On the other hand, it sometimes makes sense to present a clear perspective to the practice partners. To motivate them for co-design, an interview partner stresses the importance of showing preliminary products or services:

> You have to have something consolidated […], a preliminary product that will be ready for discussion. And then, you have to do some kind of investigation about impacts and potential services and with this preliminary idea you can go to some stakeholders and then start the discussion […]. You need to have something to show them (interview 6).

Table 1
Challenges of co-creation and suggestions for best practices.

Challenges of co-creation	Key questions	Problematic situations at the science-practice interface	Best practices
Adequate entry points and continuity of co-creation	In which stages of a research project does the involvement of practice partners make sense?	The aim of early engagement can be in tension with funding conditions and the motivation of practice partners.	A clear and realistic outline of project goals and potentials can motivate practice partners.
Competencies, skills and training	Do researchers feel well prepared and where can they acquire the expertise, skills, and experiences to conduct co-creative research?	Experiences of scientists in the domain of co-creation vary to a large extent.	Tandems of experienced scholars of co-creation with newcomers can help to create co-creative skills.
Mutual understanding	What are appropriate formats, methods, and tools to develop a shared language?	Misunderstandings can arise due to the multiplicity of concepts and the use of technical terms.	At the beginning of a project, providing enough time to clarify key concepts can foster mutual understanding.
Integration of practitioner's realities	How can practice-based needs be integrated to tackle real-world problems?	Practice partners are embedded in real-world contexts that may differ from scientific contexts.	A comprehensive analysis of practitioner's contexts can help to integrate their needs into the project.
Balancing influence	Who is authorized to take which decisions in the project?	Practice partners may have varying capacities to express their concerns.	Transparency and enough space to negotiate decision authority can help to balance influence in a fair manner.

Furthermore, it's often suggested, that scientists should maintain open towards the needs of stakeholders to tailor the project flexibly to their demands, even at a later point in the project. Yet, getting practice partners on board and, above all, have them regularly involved is sometimes difficult to achieve, as we see in the following interview quote:

> We would like to engage them as much as possible. And we would be very happy if they were in all of those parts […]. It's not we researchers that set the limitations for how much they can be involved. I think it's how much the stakeholders can and are willing to be involved. That's the agenda (interview 1).

Corresponding to some of the interviewees, an early involvement of practitioners is broadly demanded in literature (Vaughan and Dessai, 2014; Wall et al., 2017). In the early phases, the topics, questions, and methods of a project are still subject to adjustments. Here, practice partners can play an important role in contributing their perspectives. Despite the aim of researchers for close collaborations with practice partners at the beginning of projects, institutional constraints often only allow for engagements in later phases. The readiness of practitioners to join a project in an early phase also depends on their schedules and availability. Funding conditions within academia can, of course, impede the organization of projects at early stages. Still, challenges of motivating the practitioners can arise if it is not clear for them how they will benefit from the envisaged climate service product.

4.2. Competencies, skills and training

Another challenge raised by our interviewees relates to the competencies that are needed to conduct co-creation activities in meaningful ways. Our analysis shows variable degrees of expertise in this regard. Two of the respondents even reported about no prior experiences at all. An example:

> And one thing, which is also quite a trouble […], I mean the people responsible for stakeholder interaction, me and my colleague, we are not social scientists. I mean my background as meteorologist. And for us it was quite new to do the interactions with stakeholders (interview 4).

Like in this quote, co-creation activities are often attributed to social scientists by our interviewees. Furthermore, the social scientists in our sample seem themselves rather comfortable to engage with practitioners, given their training in empirical social research:

> For social scientists, I think, it's part of our work, usually. We're used to engaging with stakeholders. That's part of what drives us and what informs our research. So, it goes hand in hand. But for others it's really not something that they have experience with or a reward system really in place to facilitate that or the skills (Interview 2).

Besides institutional aspects, such as the research field, reward systems or learning opportunities, individual characteristics are seen as just as important by our interviewees. In the following quote, a researcher points to special personal capabilities as a prerequisite for successful co-creation:

> You have to like working with people. I think you have to be a bit curious. That yoúre willing to cross the boundaries of your own research field. And patience. And be of course a person, that can establish forms of trust and establish open dialogue. And you have to be, in that sense, good at having a discussion" (interview 10).

Knowledge about methods, tools and theories of co-creation as well as hands-on skills from project work differ among our interview partners. The quest for establishing more special training courses and academic reward systems for co-creation has been frequently addressed in research policy and the academic literature alike (Guimarães et al., 2019). What is more, co-creation activities include a broad range of competencies, which also depend on individual capabilities, values and attitudes. The practice of co-creating climate service products with extra-scientific practice partners emerged only during the last decade in climate change research. Hence, facilities to learn about how to organize joint knowledge production at the science-practice interface are only recently put in place in a comprehensive manner. The integration of local, traditional and contextualized climate knowledge in climate service product development is likely to fall short if there is no systematic training for practitioner engagement.

4.3. Mutual understanding

Researchers in the realm of co-creation are exposed to extensive correspondence and exchange among heterogeneous actor groups. Limitations at the science-practice interface regularly are due to the plurality of languages used within scientific disciplines, policy circles and different practitioner groups. A scientist describes the following:

> You need to talk to a lot of different people with very different perceptions and different languages. And this takes a lot of time. […] You feel like you have to repeat everything again and again (interview 8).

How misunderstandings can impair discussions in a project is articulated in the following statement:

> I mean in the end it's the language. For us, one word like 'uncertainty' has a meaning. And when you go with the users the meaning is completely different. […] And this kind of different languages sometimes is a challenge. Because sometimes you are not sure about what you are discussing (interview 6).

Communicating between different academic disciplines is a challenge in its own right. When scientists from different disciplines engage with diverse practitioner groups, this challenge is further aggravated. Here, finding shared definitions and intelligible terms can be exceedingly difficult. This challenge of finding common terminological ground is one of the most often discussed limitations of co-creation in the literature (Bergmann et al., 2015; Schuck-Zöller et al., 2018). Above all, different concepts of "uncertainty", as described above, are widely acknowledged as potential barriers (Otto et al., 2016).

4.4. Integration of practitioners' realities

Closely connected to different languages and mutual understanding are different backgrounds and perspectives of the participants in co-creation. Practice partners usually have their own priorities concerning the relevance of facts, assumptions and values that should be taken into account in climate service products. In the following quote, an interviewee points to this challenge:

> The problem is that for the scientists they need to understand the interest of the water reservoir manager. This manager has the scientific knowledge. But, he also cares about the economic value, the profits, and these other aspects that come into the conversation. That maybe a scientist doesn't have the experience to handle (interview 5).

In this regard, barriers for the uptake of climate services most likely shine up due to the complexity of scientific findings on the one side and the quest for usability on the other. This aspect is articulated in the following quote:

> For this mobile phone app […] From science point of view, we […] tried to cover all the scientific aspects. However, from users point of view, we need to consider usability. Usability, simply said, is: we have to make an app at the interface as simple as possible. […] So it́s not easy to find a balance. If we make it too simple, we have to compromise the accuracy of the heat stress assessment and the risk assessment. But if we include everything, then it's too complicated and the users don't want to use it (interview 11).

Different working rhythms and timeframes are another challenge as articulated in the following quote:

> Scientists tend to be slower and careful and like to explore the uncertainties in the data sets, make sure that what they are providing is rigorous. While the companies want the information, which seems possible. […] So this tends to be a difference in terms of timescales (interview 7).

The aspect showing up in the citations above relates to different timeframes in which science and practitioner groups are working in. In the quote above, we see a rather slow pace in the context of scientific practices due to the aim for sound and robust results. On the other side, practice partners are often working in contexts of urgent decision-making and tend to prefer. Matching these timeframes could lead to trade-offs, if practice partners have to make decisions on the basis of an insufficient knowledge base or if scientists are urged to provide knowledge that hasn't been proved viable yet. Furthermore, Brasseur and Gallardo (2016) indicate another time-related barrier in co-creating climate services: the long time frames climate projections are dedicated to. Whereas societal needs often aim at sound climate information on very short ranges like one to 10 years, climate projections usually entail longer time frames.

On the whole, the citations show how scientists are required to dive into the realities of practice partners in order to reflect their perspectives, needs and constraints. For political, economic or civil society actors, adaptation measures are often embedded in a broader set of activities and concerns. Climate adaptation adds up to their daily routines. This challenge is even aggravated by the rather informal and experience-based knowledge of practitioners, which often becomes tangible for science only through intensified deliberation. It is – overall in the community – seen as very demanding to integrate the different kinds of knowledge (scientific, solution and target oriented knowledge) during the co-creation process (Hoffmann et al., 2017). Practical experiences in different areas of societal life have to be harmonized. A special research field has emerged on knowledge integration over the last decade (McDonald et al., 2009; Hoffmann et al., 2017).

4.5. Balancing influence

The fair, equitable and transparent distribution of influence is another challenge to be acknowledged. Problematic situations can, e.g., arise due to an uneven balancing of influence between different practice partners. A challenge is therefore to recognize disputes between actor groups at an early stage:

> The agendas of one group may shape the overall research agenda to the detriment of some other groups. So, if there is a group of stakeholders - ten people […] five government officials and five […] civil society participants. The agenda of the government officials will genuinely shape the overall agenda maybe in a way that the civil society representatives […] may not feel that comfortable with the topic […] Because you always find in stakeholders groups there are dominating voices and dominating agendas (interview 12).

In order to match with practical solutions, it makes sense to have indicators and variables chosen by the practice partners that want to use the climate service product:

> You as user have to define which is the specific indicator you want to have. […] The idea is not only generate temperature and precipitation, which are our traditional variables in the climate domain. But a specific indicator, a specific variable. And this is something to be defined by them (interview 3).

Co-creation always means negotiating perspectives and interests. The intensity thereof can vary in different project phases such as co-design, co-production, and co-dissemination. Scientists usually intervene in specific sectors and local contexts from the outside. Often, they have only limited insight into existing power relations between the involved actor groups. Two quite different aspects show up in the citations above. Firstly, the challenge to take different interests between practitioner groups into account and to reflect them commonly in the processes of co-creation. Secondly, the balance of decisions between researchers and practitioners is made an issue. The importance of this balance has a bit taken a back seat since Stauffacher et al. (2008) proposed a scheme of different intensities of practitioner involvement and the respective power distribution. Recently, however, Lux et al. (2019) has taken up the importance of balancing influence between research and practice again.

While practitioners' input about their needs often frame the research question in the co-design phase, the choice and application of scientific methods in the co-production phase are often more controlled by scientists. Usually, it is not easy for practitioners to acknowledge methodological limitations that do not allow for just the special sort of output for the specific variables they wish for. This barrier has to be managed carefully to maintain scientific soundness and objectivity.

5. Suggestions for best practices

In the previous chapter, we presented five typical challenges that climate researchers face in the context of co-creation. For the most part, our results confirm former findings in the literature on co-creation and climate services. We should note, however, that due to the contextuality of climate services, the relative importance of these challenges may vary between different co-creative projects. For instance, in a project where all involved scientists are already experienced in co-creation, the challenge of competencies, skills and training will be less pressing than in a project where researchers are less experienced. Vice versa, co-creative researchers may encounter issues that are not included in our set of challenges. In the following, we turn to best practices that could be applied by climate service researchers to deal with the described challenges.

Regarding our first challenge – adequate entry-points and the continuity of co-creation – our results suggest that practitioner engagement should be both *early* in the co-design phase, and *constant* throughout the co-creation process. This is largely consistent with the co-creation literature (Lux et al. 2019; Vaughan and Dessai, 2014; Wall et al., 2017). For instance, Newig et al. (2019) analyzed about 100 projects and confirmed that societal outcomes can be improved by early involvement. Similarly, experiences of climate service providers show that early engagement can foster usability and relevance of climate services (Steuri et al., 2020). However, our data suggest that in addition to the timing of practitioner involvement, adequate entry points depend on the motivation of practice partners and the availability of sustained contacts and networks. Here, it is important to avoid *stakeholder fatigue*. Among other reasons, stakeholder fatigue may occur if practice partners are approached without a clear outlook of potential benefits. As one of our respondents put it: "You need to have something to show them" (interview 6, see sect. 4). In a similar vein, Bergmann et al. (2015), (p. 36) suggest that "in the construction phase, it is necessary that the persons responsible for carrying out the project also take responsibility for its formulation and construction." The situation at the beginning of a project can thus be characterized as a ridge walk between motivating practitioners with some preliminary idea and remaining as open as possible to their preferences. In order to motivate practitioners to join a project, and to maintain a reliable relationship once the project is running, it is important to develop an outline of intended results. This outline should be clear, transparent and realistic. Preliminary ideas can be useful to get practice partners on board, but the final agenda should be co-designed by all participants.

Our second challenge – competencies, skills and training – is equally important. Whereas most of our respondents possess some experience in co-creation, others are rather new to this domain. For them, it can be difficult to set up a consistent co-creative methodology, including its theoretical underpinnings, and to apply this methodology competently in a specific research context. Also, co-creative researchers have to fulfill several duties at the same time: they are expected to manage practitioner engagement and to provide solution-oriented services, but they are also expected to publish in peer-reviewed journals, present at scientific conferences, and to perform many other specialized and time-consuming activities. While scientists have professional training regarding these latter duties, they typically lack training regarding the former. In reaction to this important challenge, several platforms have been established in the last years to help scientists find appropriate co-creation methods[2]. As some of our respondents have claimed, it may also be useful to include social scientists in a co-creative team, given their experience with societal actors (see sect. 4). Similarly, Bergmann et al. (2015), (p. 37) suggest that "the disciplinary composition of a research team is of fundamental importance" to manage the different phases of a project, including specific tasks in practitioner engagement. Moreover, project organizers and institutions should actively develop opportunities to strengthen co-creative skills. One option is to provide qualification measures and to encourage exchanges between different co-creative projects. Another option is to mix co-creative teams in such a way that unexperienced researchers of co-creation work together with more experienced researchers. We particularly want to emphasize this latter best practice, as it demands the least resources and has a strong "hands-on" component.

Our third challenge refers to mutual understanding. Due to the highly specialized languages and terminologies used in different practice domains and scientific disciplines, finding common ground for meaningful conversations is time consuming and not easy to accomplish. If practice-oriented actors feel overstrained with rather abstract scientific language, they are likely to lose interest in the co-creation process. On the other side, researchers need to acknowledge that practitioners are embedded within unique contexts of meaning-making which may differ from scientific perspectives (Porter and Dessai, 2017). Moreover, professional practitioners often hold resources of knowledge, they can not express in scientific terms. Communicating with a wide range of non-academic audiences is therefore a demanding task for climate service researchers. To ensure the practical use of knowledge, different actor groups have to communicate at eye level (Schuck-Zöller et al., 2018) and reconcile shared definitions and intelligible terms. To promote this dialogue in transparent ways, constant translations across languages are particularly important to foster mutual understanding. In this regard, the capacities of practitioners and scientists to learn from each other can be enhanced if potential misunderstandings are openly discussed in early project phases.

Our fourth challenge, the integration of practitioners' realities, goes into a similar direction. In order to improve the societal impact of climate knowledge, the pragmatic contexts and the normative framings of extra-scientific practitioners have to be integrated into scientific research methods. Vice versa, when it comes to the application of project outputs, practice partners have to fit science-based services into their particular institutional, organizational and cultural environments. This can be challenging for both sides. Our interviews show that problematic situations can inter alia occur if the different timeframes of scientific and practice actors are not sufficiently coordinated. In the literature, this issue is often referred to the mismatch between long-term climate projections and short-term decision contexts (e.g. Buontempo et al., 2014; Jacobs and Street, 2020). However, our interview data suggest that diverging time-frames can also be problematic when practitioners expect quick results, while researchers need time to produce sound and reliable results. Similarly, scientists typically value precision, while practitioners may sometimes place higher value on ease of use. This can, as one respondent has claimed, result in a trade-off: "If we make it too simple, we have to compromise the accuracy […]. But if we include everything, then it's too complicated and the users don't want to use it" (interview 11, see sect. 4). In accordance with the literature, we hold that a comprehensive analysis of practitioner's pragmatic contexts is part of a best practice to ensure project relevance. This also includes the knowledge that practitioners can contribute to a project (Hoffmann et al., 2017). Yet, we also emphasize that practitioner values such as ease of use have to be carefully balanced with scientific values such as precision. Co-creative teams should discuss this balancing jointly and equitably. Concrete strategies to ensure this balance include – on the scientific side – the transparent explanation of the scope and limitations of scientific results for practical usage. In order to enhance ease of use, the representation of scientific results should also include comprehensive visualizations. To ensure the necessary resources, sufficient time and potentially even funding should be provided in co-creative projects.

[2] For example, the Integration and Implementation Sciences (i2S) website, https://i2s.anu.edu.au/, a german website for transdisciplinary research, https://www.td-academy.org/, the td-net toolbox, https://naturwissenschaften.ch/co-producing-knowledge-explained/methods/td-net_toolbox or the website intereach.org.

Our fifths and final challenge – balancing influence – points towards potential power asymmetries in a project. Here, problematic situations may occur when interests and problem framings diverge between different practitioner groups, or between scientists and practitioners. In such situations, the question arises whether all participants have equal opportunities to contribute to the project. One of our interviewees stressed that "you always find in stakeholders groups there are dominating voices and dominating agendas" (interview 12, see sect. 4). This link between power and knowledge has also been acknowledged in the co-creation literature (Turnhout et al., 2020; Vincent et al., 2020). Due to the heterogeneity of scientific and extra-scientific actors in co-creative processes, reaching consensus about all relevant aspects and decisions within a project is not easy to achieve. Part of a best practice in co-creation is therefore to acknowledge the diversity of viewpoints and preferences, and to find cooperative ways of conflict resolution. Establishing a level playing ground is crucial in this regard. It should be acknowledged, however, that balancing influence can be a highly demanding task in co-creation processes (Fritz and Binder, 2020), and that the ways in which mutual influences play out depends on the context, topic and available resources of a project.

6. Scientists' roles and the 'boundary manager'

The tasks and responsibilities of researchers are significantly extended when it comes to science-practice engagements in climate service development. Finding new facts, assessing and interpreting climate knowledge within their scientific community and advancing the methodological and theoretical underpinnings of climate science only reflect some aspects of a much wider frame of activities. Researchers also translate information and data into customized services and products for non-scientific audiences (for example a weather app, informative websites, climate scenario maps, decision-support tools, etc.). By emphasizing societal uptake and usability of scientific results, the activities of climate service researchers also include product design and marketing, providing access to knowledge resources and tailoring services to specific target groups. They also organize and facilitate participatory processes for the purpose of integrating the perspectives of users and decision-makers and are regularly encouraged to provide scientific policy advice to inform adaptation and mitigation measures.

Due to these increased expectations, new typologies of scientific actor roles are widely discussed in the field co-creation. Scholars have extended and further elaborated on the emerging tasks, responsibilities and normative assumptions of scientists in their attempts to engage with extra-scientific practitioners (Brundiers et al., 2013; Turnhout et al., 2013; Wittmayer and Schäpke, 2014; Crouzat et al., 2018; Maag et al., 2018). These contributions empirically analyzed how roles of researchers are shaped, maintained and reconfigured. For example, Pohl et al. (2010) describe activities, which are regularly performed by scientists who closely work together with partners from practice. They differentiate between the roles of the *reflective scientist*, the *intermediary* and the *facilitator*. The reflective scientist relates to a rather traditional role of scientists within the context of co-creation. She/he provides expertise according to the standards of her/his scientific discipline. The intermediary mediates between different thought styles, makes them visible and organizes them around the different interests within a research project. The task of the facilitator is mainly to foster communication between the heterogeneous partners within a project to enhance mutual understanding and learning processes.

On the basis of the challenges and best practices discussed above, we want to draw attention to a further role: the *boundary manager*. This role incorporates elements of the three roles presented by Pohl et al. (2010) and is thus particularly well-suited to tackle the challenges of co-creation. Its overarching scope relates to the importance of working out appropriate boundary conditions between scientific and societal spheres in order to implement best practices of co-creation. Boundaries between scientific and social spheres are regularly addressed by scholars of co-creation (Klein, 1996; 2021; Mollinga, 2010; Opdam et al., 2015; Pohl et al. 2019). These perspectives have also contributed to the question of how boundaries could serve as productive infrastructures for cooperative relationships between heterogeneous stakeholders from science and practice. It is suggested that the integration of different knowledge claims only becomes possible through intensified communication and translation between boundaries. Subsequently, within the realm of climate science and policy making, boundary organizations have been institutionalized to manage the hybrid resources of knowledge at the margins of scientific and political orders (Agrawala et al., 2001; Miller, 2001; Hoppe et al., 2013). These contributions conceive the management of boundaries primarily from institutional and organizational perspectives.

However, the roles of researchers are just as important in order to implement best practices of co-creation. Due to the heterogeneity of scientific and non-scientific actors, the management of boundaries becomes important in several ways. Boundaries between scientific and extra-scientific actors are not fixed and determined nor do they occur automatically over the course of research projects. They should rather be conceptualized as flexible, context specific and often disputed entities. Their effects on the quality of co-creation thus depends largely on available repertoires of managing these boundaries. The boundary manager interweaves heterogeneous domains of knowledge, moderates between different interests and motivations of project partners, and enables the translation and application of scientific results into meaningful products for a wide range of climate service users. In this sense, this actor role helps to establish productive ways to deal with the challenges that regularly occur in science-practice engagements. Furthermore, specific competencies and attitudes are important for this role, e.g. strategic competence, know-how about participatory research approaches, openness, sensitivity.

An open question, however, remains about whether researchers should themselves assume boundary management roles, or whether climate service organizations should establish genuine positions that are explicitly dedicated to boundary management. Regarding this question, Brundiers et al. (2013) argue that researchers lack time, resources and training to engage effectively in boundary management. This is why they propose to separate this task from the more conventional scientific parts in a project. In recent debates about inter- and transdisciplinary integration experts, even the establishment of a new profession is suggested (Bammer et al. 2020; Pohl et al. 2021). Within the field of climate services, Steuri et al. (2020) have argued for a "neutral intermediary" as a means to moderate between climate modelers and end-users. They highlight the importance of neutrality and suggest that boundaries between science and practice are best acknowledged if providers and users of climate services are supported by a dedicated role with sufficient resources and time. Jacobs and Street (2020) even go a step further by proposing to address the challenges of co-creating climate services on a large scale. They suggest to put forward a "well-coordinated network of trained, multidisciplinary science-climate service translators (fellows), preferably people (early or mid-career) who are highly interdisciplinary, good communicators (including in translation of science and the use of social media) and experienced in engagement practices" (ibid.: 4).

In this paper, however, we do not take a definite position on whether boundary management roles should be taken by researchers themselves or by designated, specifically trained personnel. We rather emphasize that both solutions have advantages and disadvantages. Establishing a new profession of boundary managers, as Jacobs and Street propose, may indeed foster the implementation of many of the best practices discussed above. However, such a profession is not fully established yet, and many years might pass until the networks and career paths envisioned by Jacobs and Street are available. For this reason, researchers often assume boundary management roles themselves. Consequentially, many scientists already have experiences with boundary management, particularly in the climate service realm. Our suggestion that less experienced co-creative researchers should learn from more experienced

ones in mixed teams could further strengthen this expertise. Another advantage of researchers taking boundary management roles themselves relates to their scientific core competencies, such as modelling skills and expert knowledge about climate impacts. As we noted above, the role of the boundary manager also incorporates elements of traditional scientist roles. When researchers act as boundary managers, practitioners can therefore trust that their academic counterparts possess robust and up-to-date scientific knowledge. At the same time, however, we emphasized above that being an excellent scientist and an equally excellent intermediator and facilitator can be highly challenging.

7. Conclusion

This article addressed challenges of co-creating climate services and proposed best practice to deal with them. On the basis of a series of interviews with researchers working in the funding line ERA4CS, we discussed five typical challenges that researchers encounter when engaging with extra-scientific practitioners: finding adequate entry points and ensuring the continuity of co-creation; possessing the necessary competencies, skills and training for co-creation; establishing mutual understanding; integrating practitioners' realities; and balancing influence in a project. We discussed several ways to tackle these challenges, such as clear outlines of project goals to motivate practitioners, or tandems of experienced and less experienced co-creative researchers. We also discussed the role of a boundary manager as a means to implement best practices in science-practice engagements. The main activities of this role apply to the tasks of moderation among scientific and non-scientific actors, translation between heterogeneous domains of knowledge and the application of scientific results into meaningful products for a wide range of climate service users.

More work is needed to further analyze enabling and constraining factors of boundary management within the field of climate service. More empirical evidence could clarify how the tasks and activities of boundary management are distributed among project partners and how related competencies are put into practice. Moving forward, there is also a need for comparative studies of co-creation. While we have focused on the experiences of researchers from the funding line ERA4CS, we have not compared how co-creation is carried out in different sectors, research fields or institutions, with regard to local, regional and national scales or concerning specific climate services and products. Also, it would be interesting to compare the challenges of co-creation identified for the field of climate services with other domains of co-creative research. It is, for instance, worth considering whether the larger time horizon of climate phenomena and the importance that climate projections play in climate research give rise to special challenges. Furthermore, it would be worthwhile to compare challenges in relation to the different phases of co-creation. In particular, more research on the co-dissemination phase could reveal how scientific results are translated into practical contexts. Nevertheless, shedding light on how boundaries at the science-practice engagements can be managed in a productive manner is an important step in a context where knowledge from diverse scientific and practice-oriented actors needs to be integrated for climate adaptation.

Funding

This work was conducted and financed within the framework of the Helmholtz Institute for Climate Service Science (HICSS), a coperation between Climate Service Center Germany (GERICS) and Universität Hamburg, Germany.

CRediT authorship contribution statement

Mirko Suhari: Conceptualization, Methodology, Investigation, Formal analysis, Writing – original draft. **Markus Dressel:** Conceptualization, Methodology, Investigation, Writing – original draft. **Susanne Schuck-Zöller:** Funding acquisition, Conceptualization, Methodology, Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

The authors would like to thank especially all scientists who took part in interviews, members of the ERA4CS working group "Co-Design of Climate Services with End-Users", Hanna Dunke and Richard Donecker for transcribing and coding the interviews, Simone Rödder and Vera Köpsel for helpful comments on the research design and method and Hermann Held for discussions about roles of scientists in climate research.

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