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Typologies of climate service co-creation approaches in practice

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HIGHLIGHTS

- Empirical ambiguity around co-creation and how it bridges the usability gap exists.
- Co-creation in practice does not always follow the theoretical approach.
- Three typologies of co-creation exist in practice to bridge the usability gap.
- The mode within which co-creation is embedded shapes its execution.
- Practitioners need to be aware of the typology they are applying and its risks.

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ABSTRACT

Co-creation is seen as instrumental in bridging the gap between scientific innovation in climate services and their use in decision-making. However, there has been limited engagement with the different types of co-creation approaches that exist in practice, how they are executed, how they bridge the usability gap, and in what situations they would be most effective. This study aims to characterise climate service co-creation in practice, and develop typologies to explore how they bridge the usability gap. We conducted Thematic and Ideal Type Analyses of 33 case studies developed from Key Informant Interviews and Content Analysis of co-creation process documents.

We show that i) co-creation approaches place a strong emphasis on the climate information (its usability and usefulness) to improve use of climate services, ii) co-creation in practice deviates from the theoretical approach, and iii) in addition to other contextual factors, the mode (research and commissioned) of co-creation has a strong influence on the execution of co-creation processes. We develop three typologies of climate service co-creation in practice; i) information-intensive (n = 21), concerned with producing useful information; ii) functional-use intensive (n = 5), concerned with the usability of the co-created information in decision-making; and, iii) innovation-oriented (n = 7), concerned with embedding new insights into innovative climate services.

This study benefits researchers and practitioners implementing co-creation in the field of climate services to understand the types of co-creation that exist, the risks associated with each type, and the level to which each type may influence the use of climate services.

Practical Implications

Co-creation approaches are increasingly applied in the development of climate services to help bridge the usability gap and to ensure these not only provide information that is useful, but also that they are used in decision-making. It is, however, important to understand that there are different characteristic co-creation approaches in practice. This understanding is important as it helps better support and position co-creation as an effective way to bridging the usability gap.

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In this study we find that there are differences in how co-creation is executed in the context of climate services that are developed as part of research projects (research-mode), and in climate services that are commissioned by end-users (commissioned-mode). Understanding how each of these modes influences the execution and outcomes of co-creation is important for practitioners and researchers implementing alike. This is because the mode of co-creation allows for practitioners to identify the margins within which a co-creation process may operate, in terms of the team sizes, how initiation occurs, the types of disciplines and teams needed, as well as the likely durations. This may allow for more intentional planning and efficient allocation of resources.

The three typologies of co-creation that we found in practice focus on bridging the usability gap in distinct ways. The information-intensive type prioritises the co-exploration of needs and the co-development of climate information, and results in a climate service that provides useful information. The functional-use type prioritises the co-design, co-evaluation, and co-delivery of the climate service aiming at improving the usability of the climate service in decision-making. The innovation-oriented type has an added stage associated with identifying contexts for innovation, dedicates time to both the process of co-creation and the climate service under development, and results in an innovative service with useful and usable information.

Typologies of co-creation help to understand how co-creation processes evolve when attempting to create a climate service that is used in decision-making. Each type of co-creation approach has its risks and opportunities when it comes to bridging the usability gap. Practitioners need to familiarise themselves with the factors that influence the trajectories of co-creation processes, monitor and evaluate their ongoing processes to ensure that they position their processes in a way that improves interactions between actors and maximise outcomes. Finally, to effectively bridge the usability gap, it is also necessary for practitioners to engage contextual factors that may impede uptake and sustainability of the climate service in practice, beyond the modes and typologies of co-creation, and develop strategies to overcome them. This would require careful assessment of the contexts of the climate service development, how and when the climate service will be used, the type of end-users, and the resources at hand.

1. Introduction

The Disaster Risk Reduction sector is essential to safeguarding lives and properties as it develops strategies and practices to prevent the impacts of extreme climate events and minimise disaster risk (Street et al., 2019). Given its role in ensuring civil protection, it is not enough for decision-makers in the sector to merely have access to useful and usable climate information. Climate services that transform climate-related data into useable products to guide decision-making, need to be used if they are to benefit society and live up to their value proposition (Sánchez-García et al., 2022). However, the current state of climate service use in decision-making leaves much to be desired owing to mismatches between the information produced and the needs of decision-makers (Vincent et al., 2020b; Hirons et al., 2021; Rubio-Martin et al., 2021), be it in format, scale, or relevance (Vaughan and Dessai, 2014; Sultan et al., 2020; André et al., 2021). As a result, climate service practitioners have embraced new approaches to climate services development, to ensure that end-user needs are incorporated.

Co-creation has been framed as an effective approach to involve users in the development of climate services that are salient, legitimate, and credible (Bojovic et al., 2021; Chiputwa et al., 2020; Boon et al., 2025); these being pre-requisite characteristics for climate services to be used in decision-making (Cash and Belloy, 2020). This approach has gained popularity among practitioners as a way to effectively bridge the current usability gap in climate services. However, co-creation is not homogeneous in how it is perceived and practised (Carter et al., 2019; Daniels et al., 2020). Evidence of diverse applications of co-creation is recorded in both grey and academic literature (Bharwani et al., 2024; Cantone et al., 2023; I-CISK, 2022; Vincent et al., 2018). There is need to engage the heterogeneity of co-creation in practice to better capture the true applicability and gain a deeper, more nuanced appreciation of the concept.

Currently, guidance around co-creation is presented with understandable care in both definition and structure to avoid imposing a specific process and how co-creation should be executed (Suhari et al., 2022). However, this has added to both the conceptual and empirical ambiguity of the co-creation concept, and a challenge in distinguishing co-creation from general participatory processes (Lemos et al., 2019; Suhari et al., 2022; Terrado et al., 2023). With such ambiguity and a lack of examples on how it bridges the usability gap, the concept of co-creation is slowly approaching buzzword status for when people from different backgrounds interact. This presents a challenge in both literature and practice when it comes to showing the value of co-creation in bridging the climate service usability gap.

There is urgent need to engage heterogeneity in the practice of co-creation if co-creation is to be presented as a functional framework where improving the use of climate services is concerned. Yet, academic literature is still lagging behind when it comes to distinguishing the approaches to co-creation that exist in practice, how they bridge the gap between innovation and use, and the contexts they are most useful in (Tarchiani and Bacci, 2024). In this case, typologies of the co-creation would offer a way to better understand different approaches and their efforts to bridging the usability gap in practice, through identifying clusters of such co-creation approaches, and organising them according to their within-group similarities and between-group differences (Stapley et al., 2022).

In this paper, we characterise approaches to climate service co-creation in practice; and develop distinct typologies of co-creation that exist in the same context. We conceptualise co-creation following Brandsen and Honingh (2018) as an all-encompassing process where the end-users are involved in all stages of co-creation, and include literature on co-production and other related co-concepts (section 2.3) in our framing. We thus build on works by Bremer and Meisch (2017) who provided the prism of co-production in climate science, Carter et al. (2019) who conceptualised co-production as a spectrum, and Fleming et al. (2023) who unpacked the applicability of co-design, co-development, and co-delivery concepts in practice.

In the following section (section 2) we outline a broader understanding of co-creation from the literature. We then outline the methods (section 3), and present the characteristics and typologies of climate services co-creation processes found in practice and their analyses (section 4). We discuss (section 5) the meaning and implications of our findings, and conclude (section 6) by highlighting the potential of co-creation in influencing the use of climate services, and cautioning researchers and practitioners to be aware of the strengths and limitations of each type of co-creation before, and during the process.

2. Characteristics of co-creation in theory

2.1. Aims of, and actors in co-creation

Bremer and Meisch (2017) conceptualised co-production processes along a prism based on their aims and outcomes. They distinguished eight types, such as those that aim to extend science, build adaptive capacity in government institutions, facilitate social learning, and empower traditional knowledge systems for governance, to name a few. In this paper we specifically engage with co-creation approaches that would fit under the iterative interaction lens, which aims to bridge the existing gap between climate service provision and use, through facilitating iterative interactions between actors (Bremer and Meisch, 2017) on the climate services value chain. Various types of such usability gaps exist. Raaphorst et al. (2020) described usability gaps using three key

usability parameters i.e. validity, readability, and interactivity at four levels i) stakeholder, ii) purpose, iii) information, and iv) visualisation format. These help in targeting and addressing specific problems in usability when co-creating climate services.

In this context, the climate service value chain depicts the movement and transformation of climate-related data and information from one actor to another into a tailored and context specific climate service (Hewitt and Stone, 2021; Dasgupta et al., 2025) (Fig. 1). The value chain begins with data providers for example, the European Centre for Medium-Range Weather Forecasts (ECMWF) and European Union's Copernicus Programme. Thereafter, it moves to data integrators which may be modellers and researchers, and to service providers which may be government meteorological departments or universities. From there, the data moves to service purveyors which include private businesses responsible for tailoring specific information. Finally, the chain ends with the users which may be various sectors of government or ordinary citizens (Fig. 1). Generally, the actors on the value chain may have more than one role depending on the process at hand, which adds a layer of complexity to the engagement of actors in co-creation processes. Additionally, while we present the actors on the value chain in a linear fashion (Fig. 1), in reality the interactions and interdependencies between the actors may also present in a manner that resembles a nested network of actors interacting (Hewitt and Stone, 2021; Neset et al., 2021).

2.2. Principles guiding co-creation

Typically, co-creation is meant to be governed and conducted following guiding principles that ensure efficient engagements between the actors involved. Several scholars have described good practices for effective interactions and recommend activities such as joint problem framing, use of accessible language, and formalising roles and responsibilities of actors (Briley et al., 2015; Bojovic et al., 2021; Sánchez-García et al., 2022; Fleming et al., 2023). Others highlight the importance of frequent communication, continuous engagement at each stage of the process, and building relationships between actors as key in conducting co-creation (Bojovic et al., 2021; Terrado et al., 2022; Fleming et al., 2023; Boon et al., 2024). Vincent et al. (2018) conducted an extensive literature review on process and product principles, and highlighted that co-creation processes should be i) flexible, ii) collaborative, and iii) inclusive. Inclusivity relates to the involvement of relevant actors on the value chain and inclusion of different knowledge systems (Vincent et al., 2018). Collaborative processes entail empathy from all actors involved and necessitates building and sustaining of relationships throughout the process (Vincent et al., 2018). Flexibility is essential in iterative engagements and relates to making necessary modifications to the process as needed and recognising that prior fixations to the process progress contradict the essence of co-creation (Vincent et al., 2018).

2.3. Stages of co-creation

What distinguishes co-creation from other kinds of participatory science is how the process moves beyond user engagement to include intentional involvement of actors in a collaborative and iterative manner, facilitating joint ownership and empowerment of all actors (Laudien et al., 2019; Bojovic et al., 2021; Vincent et al., 2018). However, the concept of co-creation is contested as it is sometimes conflicted with terms describing similar processes occurring in practice, such as transdisciplinary science, co-production, co-generation, co-development, co-design.

Scholars have developed frameworks to detail and guide the practice of co-creation in the climate services field. While these frameworks in both grey and academic literature include different number of stages defined differently (Table 1), we concur with Fleming et al. (2023), and maintain that how the stages are termed is inconsequential. Rather, we

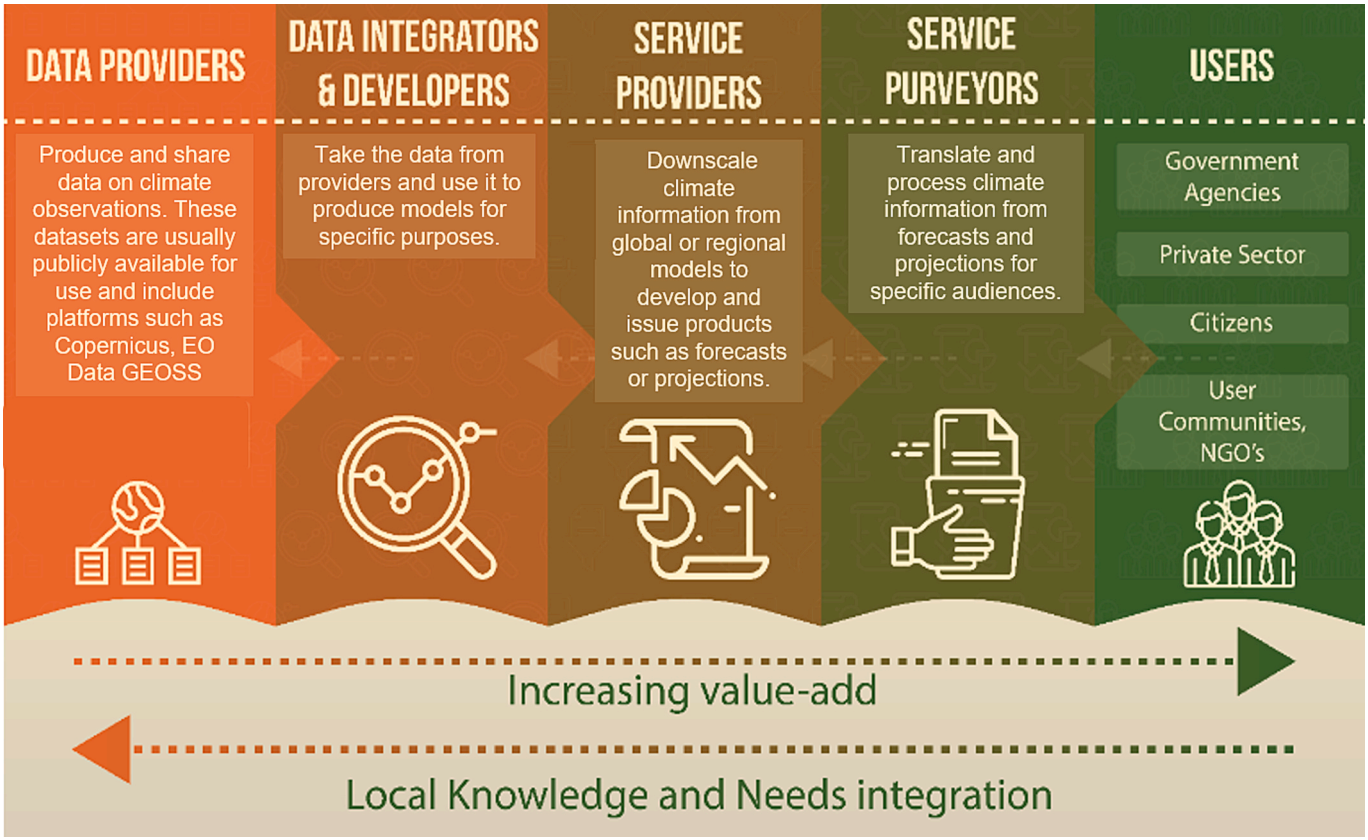

Fig. 1. Actors on the climate service value chain (adapted from Dasgupta et al., 2025) Lines 104–112.

Table 1
Descriptions of the stages involved in the co-creation cycle in climate services development.

Stage of the co-creation cycle	Description	Reference to stages in other frameworks
Co-initiation of the process	This is the beginning of the process, actors on the climate services value chain select and make agreements on who is to be a part of the process. This stage includes empathising on the challenges brought forward, and setting intentions to co-create a solution.	• Identification of actors and building partnerships (Vincent et al., 2018); Engaging and scoping (André et al., 2021); Scoping and reviewing vulnerability (Bharwani et al., 2024); Building continuous interactions (I-CISK, 2022); Co-design (Cantone et al., 2023); Co-design (Fleming et al., 2023).
Co-exploration of end-user needs	This stage involves actors unpacking and familiarising themselves with the decision-making contexts and processes. The characteristics of the information needed for the decision-making are discussed and negotiated.	• Co-exploration of end-user needs (Vincent et al., 2018); Engaging and scoping (André et al., 2021); Co-explore (Bharwani et al., 2024); Co-explore user needs (I-CISK, 2022); Co-design (Cantone et al., 2023).
Co-development of climate information	This stage involves developing new relevant knowledge and tools to better address the information needs identified. It may also involve the development of possible ideas for products and outcomes desired to address the end-user needs.	• Co-develop solution (Vincent et al., 2018); Co-develop climate information (I-CISK, 2022); Co-development (Cantone et al., 2023); Co-design (Bharwani et al., 2024); Co-development (Fleming et al., 2023).
Co-design of climate service	This stage involves the translation of end-user needs and interests into a climate product as idealised in previous stages. In this stage the technical aspects of the climate products are deliberated and tailored to how the service will be used.	• Co-design (I-CISK, 2022); Co-design (Bharwani et al., 2024); Co-develop solution (Hirons et al., 2021).
Co-evaluation of the climate service	This stage involves actors on the climate service value chain developing and applying criteria to assess the quality of the services and its outputs.	• Co-evaluation (I-CISK, 2022); Evaluation (Vincent et al., 2018); Co-explore (Bharwani et al., 2024); Co-exploration of end-user needs- identification of specific parameters (André et al., 2021); Co-evaluation (Cantone et al., 2023).
Co-delivery of the climate service	This stage involves preparation and ensuring that the climate service created may be applied in decision-making. It involves ensuring that the end-users are able to understand and convey the message from the service, capacity building and the maintenance and sustainability plans for the climate service.	• Co-delivery (I-CISK, 2022); Co-delivery (Fleming et al., 2023), Co-delivery (Cantone et al., 2023); Communication and monitoring (André et al., 2021), Co-delivering solutions (Vincent et al., 2018).

consider the activities done under each term to be identifying factors. As such, through unpacking the activities described under each stage of these frameworks, we identify six activities associated with co-creation of climate services with end-users (Fig. 2) (Table 1). These are stages associated with i) introducing actors and familiarising with the context, ii) exploring end-user needs, iii) developing a solution to the information needs, iv) designing the climate service, v) evaluating the climate service, and vi) delivering the climate service.

Based on the distinct stages, we define co-creation as a collaborative process including intentional engagement, and involvement of two or more actors on the climate service value chain from either public or private institutions in the development of a tailored climate service through an iterative process involving i) co-initiation of the process, ii) co-exploration of user needs, iii) co-development of a solution, iv) co-design of climate services, v) co-evaluation of the service, and vi) co-delivery of the climate service (Fig. 2). We try to maintain consistency and define the different stages to co-creation in relation to the frameworks applied in previous studies in the literature (Table 1).

3. Methods

3.1. Sampling

We applied purposive and snowball sampling to identify co-creation initiatives to be used as case studies from internet searches, academic and grey literature, and referrals (Fig. 3). For each case study we identified either the climate service providers, purveyors, or end-users who had been or were presently involved in the co-creation of climate services. We also acquired documentation on each case for Content Analysis (section 3.2).

For purposive sampling, we started with direct internet searches including grey and academic literature. Given the ambiguity of the concept of co-creation in practice, we included phrases based on the definition of co-creation in section 2.3 (Fig. 3). We used this broad definition of co-creation as an entry point and allowed for variants of the same concept in practice. Since this research was embedded in a broader research project that was operating in Europe and Africa, we limited the case studies to those in Europe and Africa to match the contexts.

We selected co-creation initiatives and organisations involved in the co-creation of climate services. We intentionally included cases that were occurring within and outside research, as well as those that were creating climate services for both public and private use to better reflect on co-creation in practice. For snowball sampling we applied a referral approach from the initial participants selected through the purposive sampling and from our networks, including the European Commission's funded I-CISK project consortium members (Fig. 3).

After sampling the participants, we requested further documentation of the co-creation processes from participants for Content Analysis. In cases where the invited participant was not available for an interview, we used only the co-creation documentation as part of the study, restricting only to those cases whose documents had sufficient information to fulfil the questions in Supplementary Table 1.

3.2. Key informant interviews and content analysis

We obtained ethical clearance from the board of ethics at Delft University of Technology to conduct this research with the sampled participants. Between October 2023 and February 2024, we conducted online semi-structured key informant interviews with 22 participants in Africa (9) and Europe (13). Participants were distributed between purveyors, providers and users of climate services. Interview questions were divided into two key groups, i) the climate service being developed and co-creation processes, and ii) how the different stages of co-creation (Table 1, section 2.3) that were said to have been executed in practice (Supplementary Table 1). The interviews were recorded with the consent of the participants and took between 45 mins to an hour. To maintain anonymity of the participants, each case was given a numerical code. We combined these interviews with Content Analysis of documents on the co-creation cases selected, and made use of the same questioning as the interviews (Supplementary Table 1). In total we obtained information for 33 case studies on co-creation process (Fig. 3)

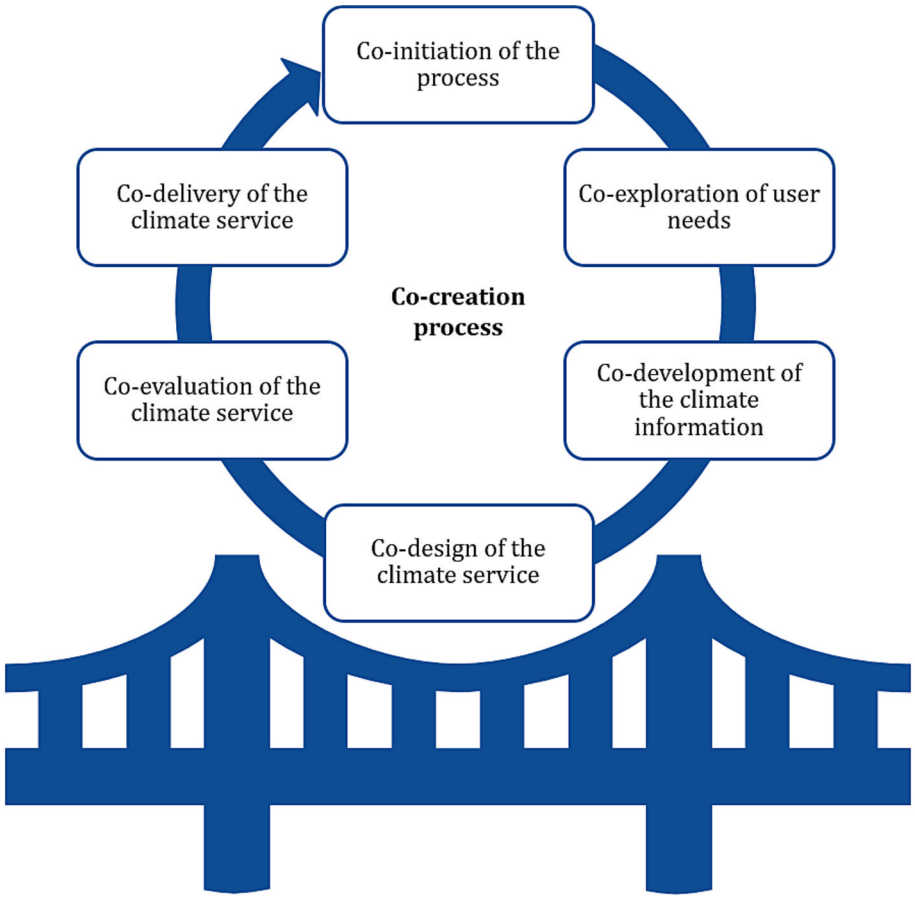

Fig. 2. The different stages involved in the cycle of co-creation. The bridge illustrates the bridging of the usability gap. In practice it is possible for the stages of co-creation to occur outside the order presented here and to follow an iterative rather than a linear process.

(Fig. 4) (Supplementary Table 2), 11 of which did not have an accompanying interview conducted as the potential interviewees were not available. The type of climate services varied from tailored climate forecasts to decision support tools for specific sectors.

3.3. Thematic and ideal type analysis

We synthesised information from the interviews and the content analysis and applied two types of data analyses. The first analysis was to determine the characteristics of the co-creation approaches in practice. For this, we applied both deductive and inductive analysis using the Braun and Clarke's (2021) thematic analysis method. We identified themes associated with the, mode of co-creation, aims of co-creation, principles of co-creation, and the stages of co-creation (Section 4.1). We applied the Ideal Type Analysis method to determine the typologies of co-creation in practice using the case reconstructions from the synthesised information. This method consisted of seven steps, further elaborated in Fig. 5.

Ideal Type Analysis is a systematic method to develop typologies through identifying, grouping and organising clusters of processes according to their similarities and differences, both within and between groups (O'Neill et al., 2021; Stapley et al., 2022). In this case, the concept of an ideal type aims not to present a perfect co-creation approach, rather an ideal type is presented as an explanatory schema to understand co-creation approaches, and how they aim to bridge the climate service usability gap. To validate the typologies, we gave the case reconstructions of the co-creation cases to two PhD researchers. We asked them to categorise eleven randomly selected case reconstructions based on the developed typologies. We found that three case studies (020) (028) (031) deviated from the original categorisation. These cases were currently ongoing at the time of the study and difficult to locate them in a specific category since they had not started other stages of the co-creation cycle. Nevertheless, we reviewed the frameworks that were guiding these cases and categorised them based on their intended trajectory.

4. Results

4.1. Characteristics of co-creation processes in practice

Following the thematic analysis, we found that the case studies applied co-creation in ways that differed from each other. Co-creation tended to i) be split into two modes of co-creation (Section 4.1.1); aimed to increase the use of climate information in decision-making in different ways (Section 4.1.2) and; approached principles such as collaborativeness, flexibility, and inclusivity in different ways (Section 4.1.3) (Supplementary Fig. 1).

4.1.1. Modes of co-creation

Co-creation in practice was divided into two modalities based on the context which they were embedded in i) the commissioned-mode (n = 12), and ii) the research-mode (n = 21) (Supplementary Table 2) (Supplementary Fig. 1). The mode of co-creation had an influence on the co-creation dynamic, and had implications on how the co-creation process was executed Table 2).

Commissioned-mode cases were mostly carried out by companies as part of their business models to clients, which were usually users of the climate services. In this mode, the end-users initiated the process of co-creating the climate service, and had an active role in financing it. The cases in this mode also included developing climate services under

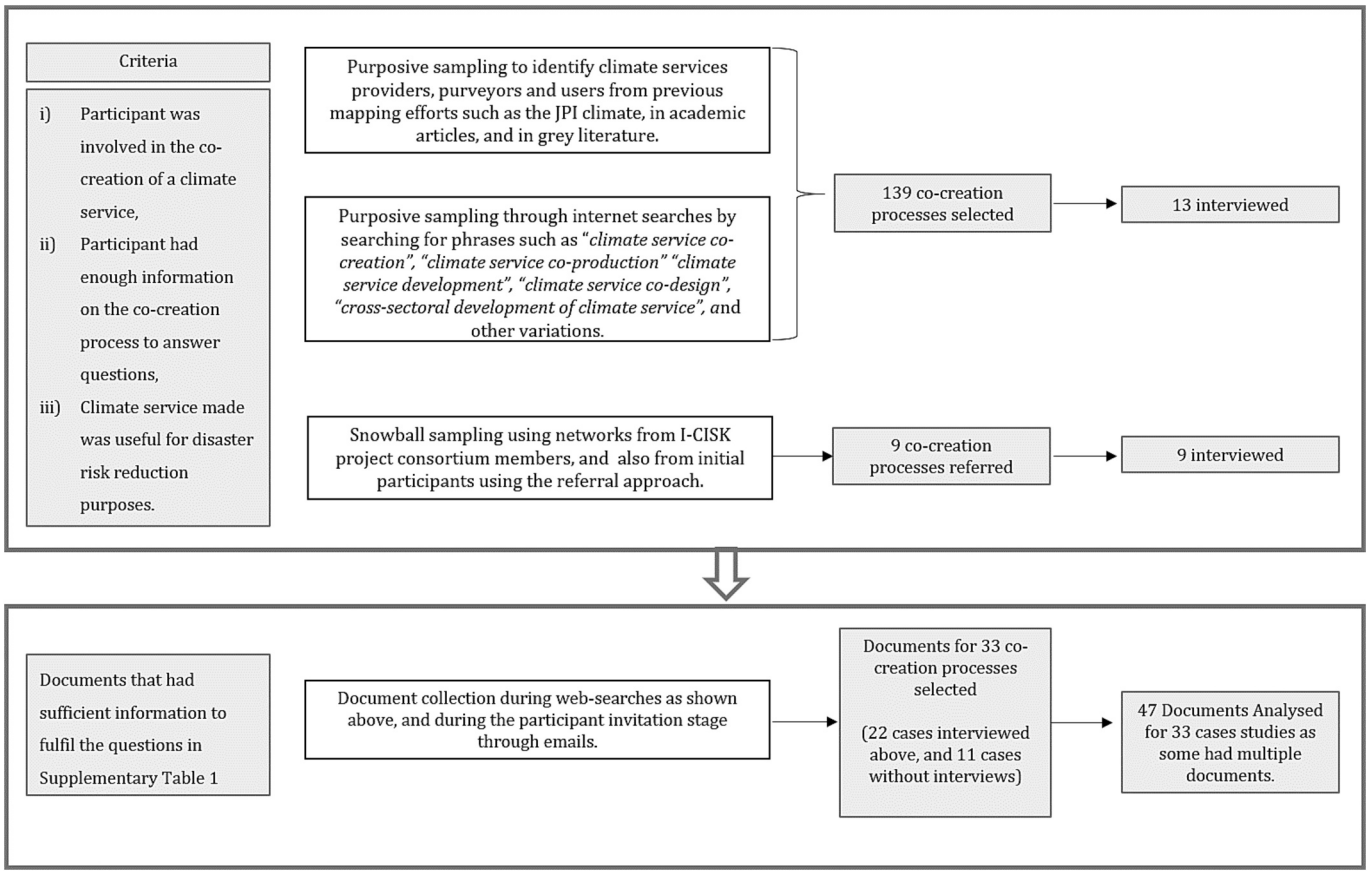

Fig. 3. Schematic representation of the sampling process.

governmental departments as part of their mandates. Additionally, the development of the climate service was the core activity of the cases in this mode, with occasional capacity building when it was needed. As such, these cases had shorter timelines and involved smaller teams (Table 2). In contrast, research-mode cases were mainly part of funded research projects led by research institutions. In this mode, end-users were approached by researchers for the purpose of co-creating a climate service, and did not have an active role in financing it. In these cases, the development of the climate service was in addition to other scientific research components. As such, they tended to have larger teams and longer timelines (Table 2).

4.1.2. Aims of co-creation

The motivations towards applying co-creation to the development of climate services were centred around enabling the use of the climate services. There was recognition in all cases (n = 33) of the need to include users in the development of climate services to ensure their use of information in decision-making. Some cases went beyond this recognition, and aimed to contribute to the use of climate services specifically through i) ensuring the climate service had information relevant to support decision-making (n = 9), ii) enhancing the climate information to support specific decision-making contexts (n = 7), and iii) ensuring that relevant end-users had access to useful and usable information (n = 1). In this one case (Case: 031) ensuring access to relevant end-users motivated the start of the process followed by the downscaling of information to the local context.

> *"But we saw quite soon that this national assessment wasn't reaching the proper level of the society. It reached the top government society and those big organisations, but we [were] also aiming to reach municipalities … the smallest municipality has about 200 inhabitants. I knew they will never be able to read this national assessment and get any real useful information." [031]*

4.1.3. Principles of co-creation

The process of co-creation, by virtue of involving actors from different backgrounds was already thought of as collaborative, flexible, and inclusive in many cases (n = 18). However, very few (n = 4) had these three principles identified and deliberated prior to the co-creation commencing. Rather, the principles were approached as responses to challenges as co-creation was already underway that is, whenever a challenge arose, solutions would then be discussed and agreed upon instead of having a clear approach to problem solving before-hand. Fig. 6 illustrates the themes developed from the thematic analysis associated with the three process principles.

4.1.3.1. Inclusiveness. Inclusiveness was largely approached through the involving of various actors in the process of co-creation (Fig. 6). A majority of cases (n = 19) (all research-mode) included various members on the value chain such as researchers from different fields, government officials, data providers, and in some cases boundary organisations. The rest (2 research-mode, and 12 commissioned-mode) included two to three types of actors, purveyors/providers and users. In all research-mode cases, the selection of the actors that were included in the process was done through existing networks and previous working relationships, and this was said to be an enabler in most scenarios. In all commissioned-mode cases, the end-users approached the purveyors/providers based on reputation, existing networks, and previous working relationships.

The type of users involved in co-creation varied. In 18 cases (12 commissioned-mode, 6 research-mode), the end-users who were to use the climate service were directly involved in the process, while in 15

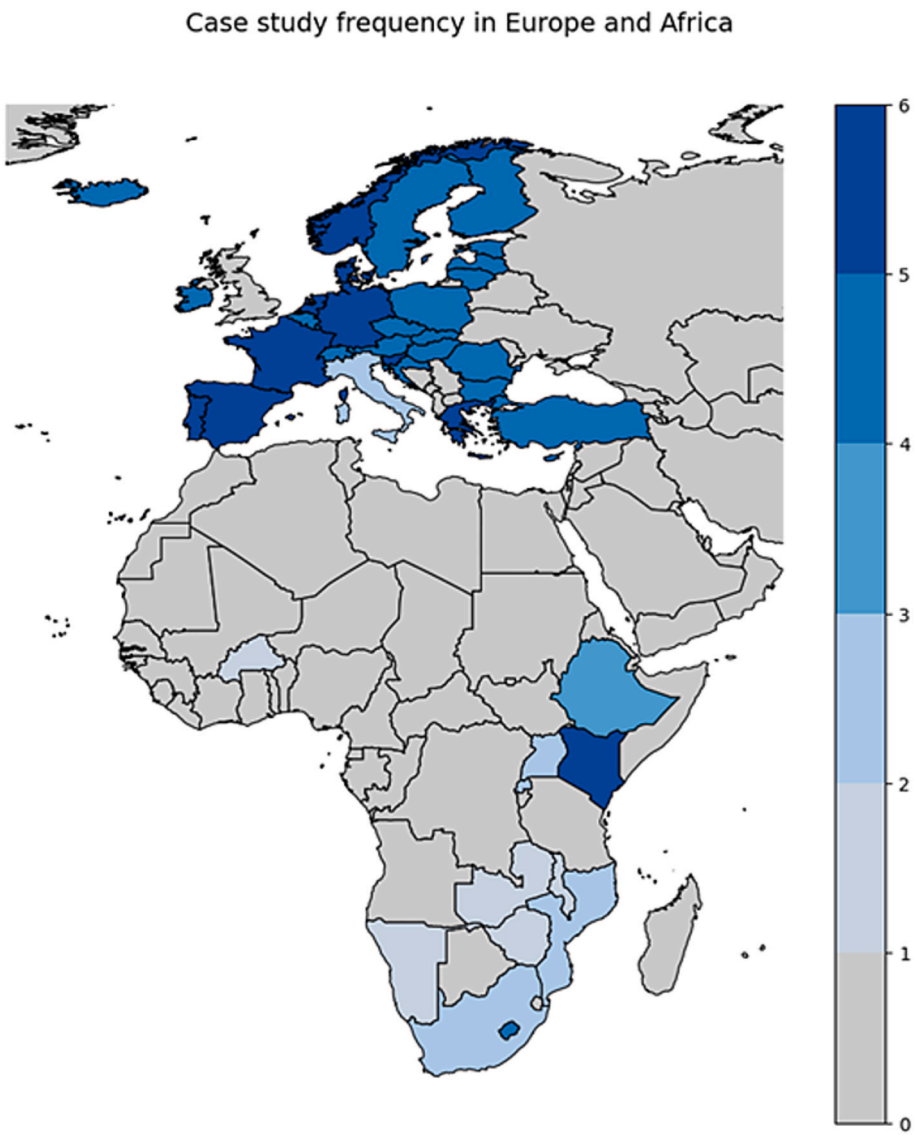

Fig. 4. Map showing distribution of case studies used in this research (Cartographer - D. Dotta Correa).

cases the end-users were included through a representative. For example, in case (028) the purveyor did not have direct engagement with the end-users, and relied on the representative to have an understanding of the end-user needs. The users involved also varied in terms of their experience and knowledge of climate services, from those who were knowledgeable to those who were new to climate services and co-creation.

Having transdisciplinary teams of scientists or different types of users in co-creation processes brought to the fore the challenge of different scientific languages in four cases (3 research-mode, and 1 commissioned-mode). In such cases, inclusiveness was shown through i) technical language moderation, and ii) allocating more time at each stage to ensure that concepts were understood. In case (006) presentation of information changed over time to make the information more digestible to the audience through the use of various visualisation and presentation approaches such as PowerPoints, infographics, and online interactive tools. Finally, inclusiveness was shown in the type of knowledge that was incorporated in climate services or considered in the discussions (Fig. 6). The recognition of non-scientific types of knowledge was evident in only one case, which was under research-mode specifically including cultural knowledge and observed climate.

4.1.3.2. Collaborativeness. The collaborative nature of the cases was related to the frequency of interactions, trust building, and having a shared understanding of the problem (Fig. 6). For a majority of cases (n = 27), collaboration was said to have ensued through frequent meetings with all actors. The frequent meetings, both online and in-person, allowed for different views to be understood, information to be communicated, and to maintain sustained engagement. However, in case study (031) (research-mode) the frequent interactions were thought of as "too much" by the end-users.

Most cases (n = 23) highlighted trust building to be a pillar for the collaborative aspects of co-creation. They highlighted the importance of trust and confidence in both the abilities of the producers to meet their needs, and the climate service being produced. Frequent communication was associated with transparency in some cases and helped build trust. Furthermore, building trust was noted to be a long and challenging process in most cases (n = 17) as it required more effort and resources. At the same time, in 16 cases, while effort was still needed, fostering trust and common ground was based on previous working relationships and existing networks as illustrated in the quote below:

> *"But there was a lot of effort building the trust. I have to tell you that the companies on board of the project they had already a trust relationship built with the respective consortium members. So, for in my case I've been*

Table 2
Factors differentiating the two modes of co-creation processes in practice.

Factor	Research-mode	Commissioned-mode
Embeddedness	Research projects.	Part of organisation operational work.
Time/duration	Longer periods (between 3–5 years).	Shorter periods (weeks to a year).
Team sizes	Larger sizes (9 + people) including various researchers.	Small (2–4 people) – medium (5–8 people) size teams
Disciplinary backgrounds of the teams	Various disciplines in academia, policy, practice and boundary organisations	Less disciplines involved: Policy, practice and in a few cases boundary organisations
Users involved (Section 4.1.3.1.)	Multiple user groups from government officials, researchers, purveyors and users.All research-mode processes except two	Less user groups with teams between 2–5 people, usually purveyors and end-users.
Initiation of the process (Section 4.1.4)	Researchers initiate the process mostly through previous working relationships.	End-users approach providers/purveyors based on existing networks and/ reputation.
Motivations	Development of climate services as part of a research project with other research objectives.	Development of climate services as core activity as part of operational activities.
Funding sources	With third party funding, e. g. EU, national or regional sources.	With basic funding/own budget. In some cases, EU, national or regional sources depending on the client/user

working with this company over 20 years. They know me, they know my work. So, I think that helped a lot." [015]

Having a shared understanding of the problem contributed to a sense of collaboration in 10 cases (7 commissioned-mode, and 3 research-mode). This was facilitated through the process of co-ideation and empathising at the beginning of the processes. Having various agreements signed with formal roles and responsibilities in commitment to the cause of co-creation contributed to a sense of working together.

4.1.3.3. Flexibility. Flexibility was highlighted in two ways i) flexibility in the process of co-creation, and ii) flexibility in the output of the process (Fig. 6). In terms of process flexibility, in some cases (n = 11) this meant that more time was allocated to some stages than others in order to have actors understand the concepts discussed. A purveyor noted: *"We had to spend a lot of time engaging with end-users to ensure that we were on the same page" [020].* However, other cases that were developing public services catering to a wide range of end-users, some of whom were not represented in the process, a rather rigid approach to co-creation was followed. A provider noted:

"*Sometimes we receive feedback. Where I am not sure if it is useful for everyone if we change the portal like that, because then I have the feeling it's like a single opinion and not helpful for everyone. And we also, I mean we are a public service, we always have to have an eye on the cost that we are causing by doing so." [017]*

This highlights the challenge in the type of climate services (public and private) and how flexibility could be approached. Negotiation on what could be delivered had the producers and purveyors communicating their limitations. Such expectation management and negotiation allowed for new insights and new approaches to be agreed upon as needs and skills shifted. In most cases (n = 19) flexibility was shown in most stages of co-creation cycle, while in others (n = 14) flexibility was limited to specific stages such as co-exploration of needs and the co-development of the climate service.

4.1.4. Stages of co-creation

Different structural variations exist to co-creation influenced by aspects such as i) end-user contexts, ii) time needed for the co-creation process, iii) mode of co-creation, and iv) availability of resources. The most commonly applied were the co-initiation, co-exploration of end-user needs, co-design, co-evaluation, and co-delivery stages (Fig. 7). However, stages such as the co-initiation stage were influenced by the mode of co-creation. In research-mode cases, co-initiation was initially led by researchers, thereafter the other actors on the value chain involved in the co-creation process would engage in co-initiation together. While in commissioned-mode cases, the end-user initiated the process usually following exposure through existing networks and previous working experiences. The co-development of information stage was only identified within research-mode cases. In other cases (n = 9) the co-development stage was combined with either the co-exploration of end-user needs and the co-design stages. There was no evidence of the co-evaluation stage in some cases (n = 9) and in these cases it was due to the type of climate service being developed. In these cases, an agreement would be made beforehand but no evaluation and revisions were carried out. The was no evidence of the co-delivery stage in 14 cases.

4.2. Three typologies of co-creation approaches in practice

Following the Ideal Type Analysis, we identified types of co-creation approaches in the practice of climate services development based on how they aimed to bridge the usability gap. We focused on the stages of the co-creation that were prioritised and had intense interactions. This resulted in three types of co-creation approaches: i) the Information intensive type, which was constituted by a majority (n = 21) of the cases; ii) the Functional-use intensive type, with five cases; and iii) the Innovation-oriented type, with seven cases (Supplementary Table 2).

4.2.1. Type 1: The information intensive

This type is centred around understanding the decision-making strategies and the climate information needed for specific decision-making processes. Interactions between actors are of a high intensity during the co-exploration of user needs, and or the co-development of climate information stages of the co-creation cycle. While all stages of the cycle are conducted, high priority is given to the earlier stages of the cycle and information needs are consistently refined over time (shaded in Fig. 8).

This is typically applied when actors are new to the climate services field and are not aware of the characteristics of the information they would need. It is also applied when enhancing information in an already existing system where a better quality is needed. This type occurs in both commissioned and research-modes of co-creation. In research-mode cases it tends to have intense meetings dedicated to awareness raising, detailing context and possible applicability of a new climate services. The co-delivery and co-evaluation stages tend to be rushed in this type. Additionally, these stages are often piled together with blurred boundaries between them. As a result, this type (Box 1) risks identifying useful and usable information, but these do not always translate to use as other stages lack sufficient attention. It is also time consuming, and sustained interest is difficult to maintain with end-users.

4.2.2. Type 2: The functional-use intensive

This type is centred around the functional-use of the climate service under development. The intensity focuses on how the climate service will be used and if the intended users are able to obtain enough information from the climate service to support their decision-making. This type is applied when enhancing an already existing service or when working with experienced users who are aware of their information needs. It exists in both research or commissioned-modes of co-creation. While the process may follow a similar cyclical structure, this type places more focus on the co-design, co-evaluation, and co-delivery aspects of the co-creation cycle (shaded in Fig. 9). In some instances, the co-exploration of end-user needs and co-development of solution are only done once at the beginning instead of iteratively.

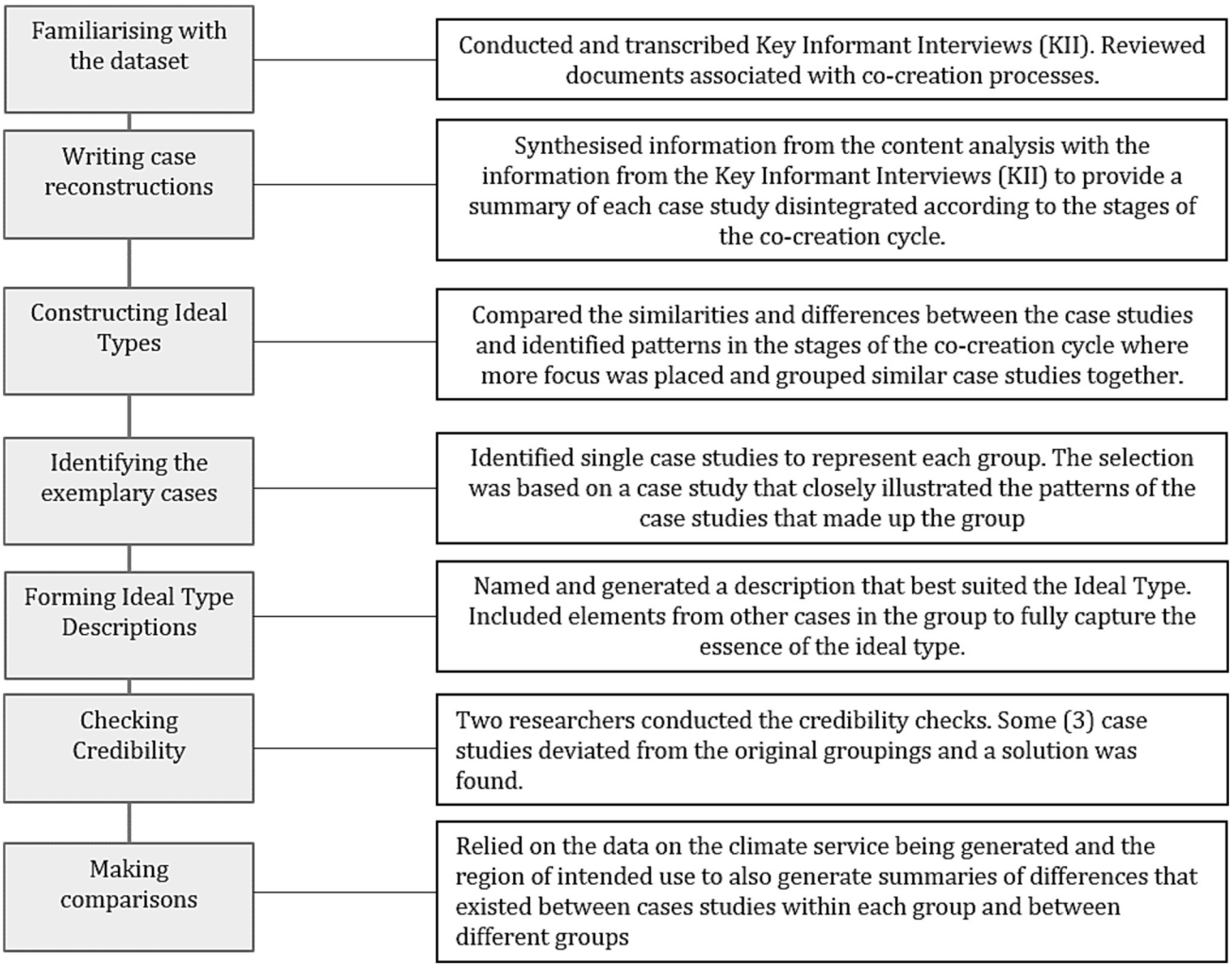

Fig. 5. Ideal Type Analysis procedure.

In cases where new services are developed, the co-design stage typically takes an agile approach where a demonstrative climate service is presented to the users early on in the process. Since end-users are able to see an example of the output earlier on in the process, it is easier to maintain actor engagement and trust in this type. However, the rushed or neglected co-exploration of needs and co-development of information stages may result in new emerging needs being neglected. This type (Box 2) also requires the end-users to be aware of their needs and have some experience working with climate services.

4.2.3. Type 3: The innovation-oriented

This type is centred around innovating new climate services through prototypes, and often occurs in research projects. The aim is to integrate fundamental science and is typically applied when developing tools that may seek to integrate various ways of knowing. It is also applied in contexts where a climate service is currently not available, and when exploring new ways to develop climate services, and make them used. This type has a structure that closely resembles the co-creation frameworks in the literature. While some stages of the co-creation cycle may be combined, the iterative cyclical approach to the development of the service is maintained. It usually has an additional stage to the process (context matching) which often occurs before the co-initiation stage and is aimed at identifying contexts suitable for the innovation (shaded in Fig. 10).

Co-initiation then occurs after the researchers have determined specific contexts that match their innovative potential or funding calls. Due to its innovative ambition, this type takes long to move from one stage to another resulting in delays, and often includes a lot of workshops for awareness raising on climate services and their potential use in the user's context. This type (Box 3) is usually project bound and suffers from continuity problems of both the developed prototype and the sustained interactions between actors. This type also risks developing innovative climate services that are not aligned with current policy which affects their uptake and is highly depended on the project timeline and funding.

5. Discussion

5.1. Characteristics of co-creation in practice

5.1.1. Mode of co-creation

Our findings show that co-creation for climate services is executed differently. The mode (research-mode and commissioned-mode) within which co-creation is embedded shapes its execution. This is consistent with literature as it is well established that co-creation is context specific and takes various forms in practice (Carter et al., 2019; Vincent et al., 2021; Fleming et al., 2023). However, the mode is rarely acknowledged as part of the contextual factors that influence co-creation. The current discussions on context are associated with geography, socio-cultural and political contexts, institutional environments, and historical contexts

Fig. 6. Themes associated with process principles.

(Daly and Dilling, 2019; Laudien et al., 2019; Vincent et al., 2020b; Swart et al., 2021). Other specific aspects considered within contexts relate to type of climate service developed, decision-making contexts, funding, and time constraints (Bojovic et al., 2021). Therefore, since the mode influences various aspects of co-creation, there is a need to acknowledge that co-creation differs when applied under research and commissioned modes. Additionally, in commissioned-mode cases, organisations have their own operational ambitions, the resulting co-creation process will depend on the level to which the organisation embeds co-creation principles in its practices while still meeting organisational ambitions.

5.1.2. *Aims of co-creation*

Our findings show that co-creation cases in practice recognise the need for users to be involved in the process of co-creation as a way to bridge the usability gap. However, they tend to place a strong focus on the quality of climate information (its usefulness and usability). Striving to create useful and usable climate information is consistent with Bremer and Meisch's (2019) iterative interaction prism, and is in line with credibility, saliency, and legitimacy of climate information being key to co-creation (Daly and Dilling, 2019). However, it is increasingly acknowledged within the literature that useful and usable climate information alone will not lead to better decisions, or use of the climate services (Vincent et al., 2020a; Findlater et al., 2021). Climate services being viewed as the only outcome of co-creation leads to a heavy focus on technical solutions, such as better-quality data rather than the institutional factors in the enabling environment. The current focus on creating useful and usable climate services will not be enough to facilitate use of climate services. If co-creation is to effectively bridge the gap between information and use in climate services, aspects of the enabling environment need to be considered as integral parts of co-creation.

5.1.3. *Process principles*

Our study shows that in co-creation cases under the research-mode, previous working relationships and existing networks are enablers for trust building, and are used in the selection of actors to be involved in co-creation processes. While precedented in the literature, co-creation still relying on previous working relationships for the selection of actors is a critical issue (Terrado et al., 2022; Visman et al., 2022a,b; Tarchiani and Bacci, 2024). Using pre-existing networks may be an easier route to

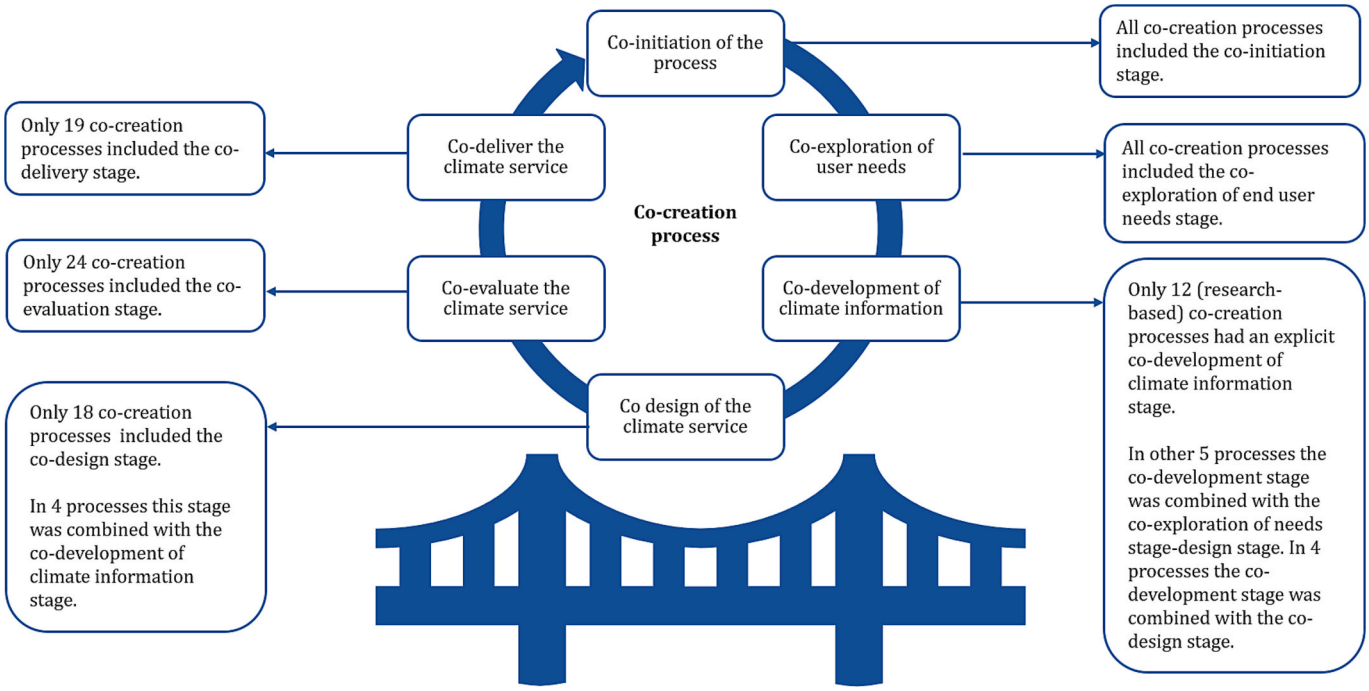

Fig. 7. Stage distribution of co-creation processes in practice.

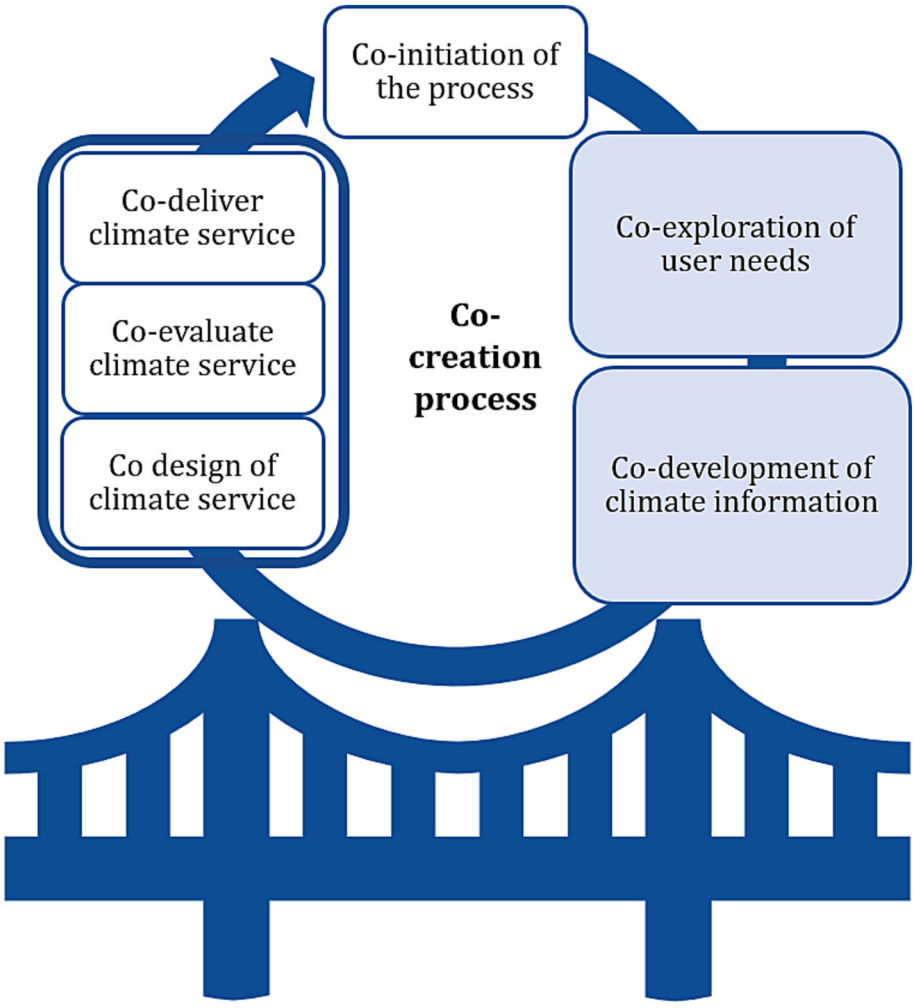

Fig. 8. The Information Intensive type, shaded stages have more priority and takes more time, while grouped stages are rushed through and clumped together.

Box 1
Exemplary case study of the information-intensive type

Exemplary case study

Co-creation of tailored aggregated flood risk and flood impact data for coastal areas [030]

The exemplary case for this type is case (030). This case was under the commissioned-mode of co-creation and the end-user reached out to the purveyor with an idea of the type of service they wanted. In this case the end-user was not very experienced with working with climate services data and it was soon realised that the type of information the user initially thought they needed was not going to be helpful for their decision-making processes and contexts: "*At the end we discovered together that they were more interested in assessing the evolution of some kind of phenomena, so very high resolution is not so useful*" [030]. The other stages of the cycle were undertaken. However, most of the project life cycle was spent in these initial stages of co-creation cycle with constant refinement of needs.

"But then when we realise that. That is not what they are looking for … and we needed to elaborate time to elaborate the needs and inputs."[030]

"So, they are not so expert in the observation data, which means that they could have a very high expectation and then we try to focus on what they really need, because sometime they start asking for a very high solution of the final product, realising that at the end maybe such kind of solution is not really needed. But maybe it's better to have a dense time series instead of a better solution." [030]

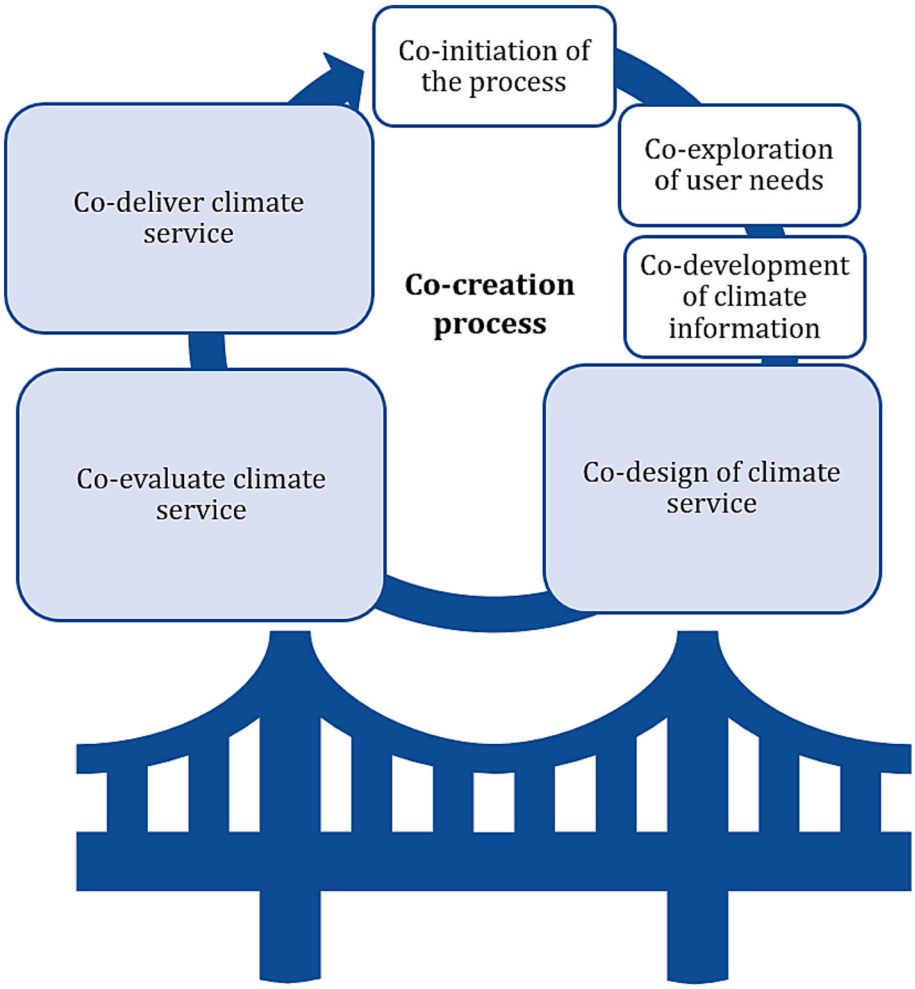

Fig. 9. The Functional-use intensive type, shaded stages have more priority and make up most of the life cycle of the co-creation process, with less time spent in the first three stages.

initiating co-creation and building trust where there are no entry points and limited time to co-creation. However, this has implications as there is a risk of excluding potential actors that would otherwise benefit from the co-creation processes.

5.1.4. Stages of co-creation

We showed that co-creation in practice does not always follow the stages of the co-creation cycle strictly and executes each stage differently. Iteration occurs only in specific strategic stages of the cycle, while other cases omit some stages. The different frameworks that exist in literature point to co-creation taking different shapes (Vincent et al.,

Box 2
Exemplary case study of the functional use intensive process

Exemplary case study-

Co-creation of hydroclimatic model and seasonal forecasts [018]

The exemplary case for this type is case study (018). This case was under the commissioned-mode of co-creation and the end-user approached the purveyor to partake in the co-creation of a climate service. Since the end-user was an experienced and knowledgeable user, the purveyor and end-user only had two meetings to co-explore needs and decision-making contexts. "*We have users that are very knowledgeable so they know exactly what they want, and sometimes they even ask us to do, for example, indicators that are customised to their needs*" [018]. Thereafter, a demonstrative service was showcased to the user, followed by an intense series of meetings centred around the design and evaluation of the product and how it would inform decision-making. Finally, the co-development stage occurred. However, it focused on uncertainty discussions and not necessarily capacity building as the user was already familiar with the product and its value. "*They already are familiar with the whole concept, and they understand better the added value and so it makes it easier to sell them stuff*" [018]. In this case a previous working relationship existed between the actors involved and actors had the same technical language.

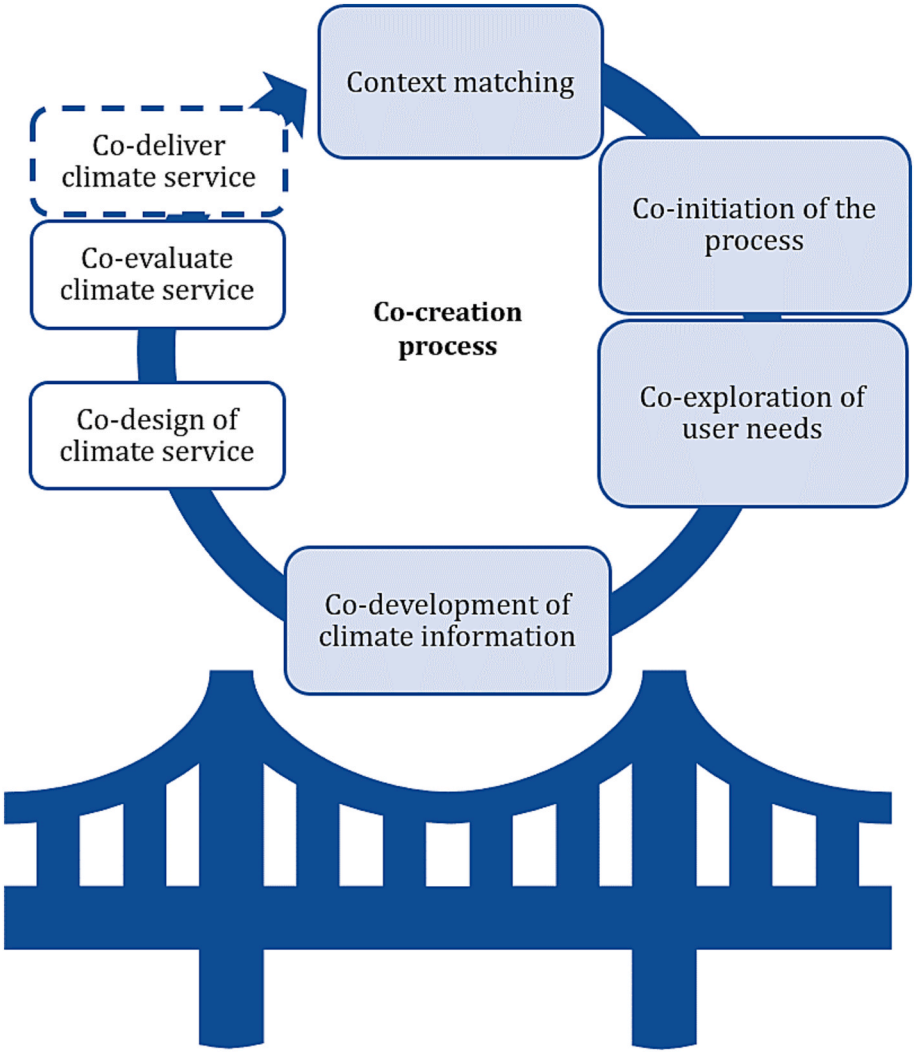

Fig. 10. The innovation-oriented type, first stage is added into the process, the earlier stages of the cycle have more time dedicated than the last stages of the cycle with the last stage skipped in most cases.

2018; André et al., 2021; I-CISK, 2022; Cantone et al., 2023; Bharwani et al., 2024). Additionally, other studies have also identified that other stages of co-creation are skipped depending on the context (Fleming et al., 2023). This may be explained by the mode of co-creation, and where the emphasis was placed in the co-creation process. The differences in the application of co-creation and its structure are based on the contexts, be it existing climate services or limited timelines to undergo all stages. However, the level of embeddedness of co-creation at different stages affects the outcome of the overall process. While this may not be to the detriment of co-creation, clarity on why some stages are skipped or combined is needed as well as understanding the risks involved with the lack of iteration and engagement with end-users.

Box 3
Exemplary case study of the innovation intensive type

Exemplary case study-

Future climate projections and tailored products for risk management [014]

The optimal case for this type was case study (014). Central to this case was the need to fulfil fundamental science that was acknowledged to still be needed in the area of climate predictions. In addition to the climate service, the co-creation process was also a part of the innovation and experts were included from different fields to ensure a multi-disciplinary team. The selection of end-users was based on prior established working relationships in order to reduce the time it would take to familiarise with new contexts. However, this was acknowledged to be limiting in terms of the areas the project would work on.

"*I would say in some ways we now balance that against interacting with places that maybe are more vulnerable or more exposed or face more severe challenges with the fact that we wouldn't end up spending the entire project getting to know our stakeholders." [014]*

The co-evaluation stages included the evaluation of the co-creation process itself. However, a great concern was that the climate service would not be used after the project due to the short lifespans of the research project as well as limited funding:

If it is [the climate service] not being used and it doesn't fit within, say, the regulatory framework that the actor is working in, then it is not really a particularly useful service. And that's really hard to do because you may not get that answer within the time span of a project. You may not get that answer within five years of a project ending [014].

Finally, the relationships and engagements were also difficult to sustain during and after the project ending, affecting the continuity of the personal interactions. The high turnover in organisations where the climate service was developed also affected the continuity of the technical aspects of the process.

5.2. Typologies of co-creation approaches in practice

We identified three types of co-creation approaches that exist in practice, centred around improving the use of climate services in decision-making. The Information-intensive type is concerned with the co-creation of useful information through emphasising information needs and developing new climate information. The Functional-use intensive type is concerned with the usability of climate information in decision-making by placing focus on the design, evaluation, and delivery of the climate service. Finally, the Innovation-oriented type is concerned with innovating new climate services through conducting and embedding insights from science, policy and practice in new climate services to make them useful.

These findings concur with Fleming et al. (2023), who showed that co-creation approaches place focus on different aspects of the co-creation cycle. The skipping of stages and lack of iteration is inconsistent with the theoretical approach to co-creation, which is meant to involve iterative interactions at all stages of climate service development; and is a fundamental aspect that sets co-creation apart from other participatory processes. We reason that the differences in the practice of co-creation and in its theory are due to several factors:

i) The difficulty in ensuring sustained engagement with the actors for sustained periods. In practice, end-users have other commitments and participation in co-creation is often voluntary. Additionally, sustained interactions have led to "stakeholder fatigue" in some contexts.
ii) A mismatch between the funding structures and allocated time, with the level of detail required to execute engagements and innovation in research-mode cases. In practice, for research projects more time is spent getting to know actors, the context, and building relationships.
iii) The assumption that the climate service is the only output of co-creation. The heavy focus on climate information and the drive towards creation of credible, legitimate, and salient information tends to favour information against other aspects in the contexts they are working in.
iv) The mode of co-creation. While co-creation in theory assumes a blank slate to co-creation processes and a collaborative approach in determining the direction of the process. In practice, co-creation is dependent on the mode in which it is embedded, which influences the structures and teams involved in co-creation processes.

All three types of co-creation approaches are centred around improving use of climate services through improving the usefulness and usability of climate information. However, they risk producing climate services that may not effectively bridge the usability gap by focusing on only a few aspects of the cycle. While co-creation in practice does not need to strictly abide by the theory, there is a need to understand the advantages and disadvantages of each typology and be contextually grounded if it is to contribute to use of the climate service. Practitioners need to understand the factors that influence the trajectory of co-creation under each typology and strategize beforehand. Such factors include the type of actor, type of service, already existing information and climate services, initiation of the process, and personnel with skills available. Finally, it is important to be aware of and understand the type of co-creation at play, the risks and opportunities involved, how to negotiate a balance between the different stages, and how to structure teams accordingly.

6. Conclusion

The concept of co-creation has been applied in the development of climate services. However, the challenge has remained that there is no clarity on how these processes lead to use of climate services beyond the inclusion of actors in the climate service development process. This study sought to characterise climate service co-creation in practice and to develop typologies of co-creation approaches based on how they aim to ensure the use of climate services. We intentionally went beyond co-creation for climate services ongoing through research projects and included those that were occurring in the business sector to reflect on the reality of co-creation in practice.

In characterising co-creation approaches in practice we identified that i) co-creation processes still focus on the climate information in the way they aim to bridge the gap between innovation and use in decision-making; ii) the mode of co-creation is a contextual factor that also shapes how co-creation is executed and how process principles are approached; and iii) co-creation in practice does not follow the theoretical approach. In categorising the types of co-creation, we classified three types of co-

creation approaches in practice, i) the Information-intensive type focussed on useful information; ii) the Functional-use intensive type focussed on usability of information and; iii) the Innovation-oriented type, focussed on innovating useful and usable information.

These findings indicate that co-creation has value in bridging the gap between climate information and use through the creation of useful and usable climate information. However, the over emphasis on specific aspects of the co-creation cycle, in addition to the poor engagement with factors in the enabling environment may limit the extent to which co-creation can help bridge the usability gap. This study is useful for the scientific community through providing three typologies which may act as lenses to unpack and understand approaches towards bridging the usability gap. Practitioners co-creating climate services will need to consider the mode of co-creation they are embedded in and how this influences the dynamic of the co-creation process that may occur, from how their teams will be structured to the duration of the co-creation process. Additionally, they will need to perform a careful assessment of the contexts of the climate service development, and thoroughly engage with how and when the climate service will be used. Furthermore, they may need to assess the type of end-user involved and ensure that their teams are structured to better engage with the type of end-users. Finally, they need to consider the typology they may fall in and ensure that the resources available are allocated in ways that minimise risks in the process and contribute to the full execution and maximising the outcomes of co-creation.

This study focused only on the co-creation approaches. Our upcoming study will unpack the types of outcomes and impacts from each of these types, and the level to which they influenced use in decision-making. Further research could explore effective measures to evaluate the different types of co-creation approaches. Finally, recognising that co-creation is demanding to execute, the typology of co-creation applied should be directed towards ensuring that the climate service produced is used in decision-making.

CRediT authorship contribution statement

Balbina Nyamakura: Writing – review & editing, Writing – original draft, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Ilyas Masih:** Writing – review & editing, Supervision, Project administration, Funding acquisition, Conceptualization. **Micha Werner:** Writing – review & editing, Supervision, Project administration, Funding acquisition, Conceptualization. **Leon Hermans:** Writing – review & editing, Supervision. **Graham Jewitt:** Writing – review & editing, Supervision, Project administration.

Declaration of competing interest

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

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.cliser.2025.100607.

Data availability

I have made supplementary information available

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