(Social) Innovation in Climate Services Provision

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Abstract

The development and adoption of climate services is a dynamic process requiring integration and social acceptance. This study explores how innovative approaches to climate service design can address usability and acceptability gaps and support their integration into urban climate risk management. Using transdisciplinary co-design methods, the study highlights the importance of engaging users to co-produce actionable and impactful services. Innovation in climate services disrupts traditional behaviours and creates new decision frameworks that help users navigate climate management cycles. The paper presents five case studies that illustrate the transformative potential of co-designed climate services in promoting adaptation and resilience. It highlights the reciprocal relationship between climate services and social innovation, with the latter fostering inclusivity and creativity. The findings underscore the role of climate services in driving social innovation and building resilient societies, demonstrating that a user-centred approach improves climate risk management and supports broader social and environmental change.

Plain language summary

Creating and using climate services is a constantly evolving process that depends on both technical integration and public support. This study looks at how new ways of designing these services can make them easier to use and more widely accepted, especially in cities dealing with climate risks. By involving different people and working together across fields, the study shows how important it is to include users in developing services that are useful and effective. These new approaches challenge the old ways of doing things and offer better tools to help people make climate-related decisions. The paper shares five examples that show how co-designed climate services can help communities adapt and become more resilient. It also explains how climate services and social innovation influence each other—social innovation brings more inclusivity and fresh ideas. Overall, the study finds that putting users at the center makes climate services more effective and helps drive positive social and environmental change.

Key points

1. Climate services require integration and public acceptance – their development is a continuous process that depends on technical and social factors.

2. User involvement is essential – engaging users through co-design makes climate services more usable and impactful.

3. New approaches improve decision-making – innovative design methods challenge traditional practices and support better climate risk management.

4. Case studies demonstrate the real-world impact of co-designed services, illustrating their efficacy in aiding cities in adapting and building resilience.

5. Climate services are interconnected with social innovation, with the latter promoting inclusivity and creativity, thereby reinforcing the effectiveness of climate services.

6. User-centred design is instrumental in driving change, leading to more effective climate risk management and fostering broader social and environmental transformation.

1 INTRODUCTION

As early as 2009, the World Meteorological Organization (WMO) had already garnered the support of 155 countries in establishing a Global Framework for Climate Services, with the stated objective of ensuring the dissemination of climate data and information to end users. In 2015, the European Commission defined climate services as science-based and customised climate change information to support adaptation to or mitigation of climate change.(Street 2016). Subsequent to that point in time, the provision of climate services has been promoted in Europe and elsewhere as a significant mechanism with which to bridge the gap between climate data and information (model predictions and projections) and decision-makers.(Street 2016).

Science-based information services e.g., climate services, are important for evidence-based decision-making in a society needing to mitigate and adapt to the impact of climate change(Lourenço et al. 2016; Street 2016). In 2012, Hallegate estimated that in Europe alone, hydro-meteorological and climate services, and early warning systems saved several hundreds of lives per year, avoiding between $596 million and 3.5 billion US$ of disaster asset losses per year (Hallegate 2012). In 2021 the WMO estimated that weather and climate services contributed up to $162 billion annually to the global economy by improving weather and climate services(WMO 2024). The benefits of using climate services are systemic and accrue in economic and social terms(Perrels et al. 2013). Their use also improves the management of environmental impacts. Climate services can also sustain the formulation of adaptation policies and support communities in transitioning towards resilience by providing customised climate information and advising possible climate futures (Giordano et al. 2020). For example, they can support selecting adaptation options for future climate-related events and conceive a vision for adaptation outcomes. A multitude of geographical areas and sectors require effective, bespoke data and resources to facilitate the formulation of strategies to mitigate perceived, experienced and potential climatic risks (Pörtner et al. 2022). Since the inception of “climate services” they have been developed and applied in various sectors and settings from agriculture to coastal and ocean systems. Nevertheless, the utilisation of climate information by the public and private sectors to enhance resilience to climate change is still in its infancy due to a useful-usability-used challenge(Dilling and Lemos 2011; Lemos, Kirchhoff, and Ramprasad 2012). After almost two decades of climate service production, research and experimentation, there is an urgent need to accelerate the provision of climate change information to support climate risk management (Clifford, Travis, and Nordgren 2020). The volume, coverage and resolution of climate change data and information have continued to grow but questions and challenges to their use in practice remain. Particularly, those relating to the usability, accessibility and acceptability of the wealth of information to contribute to local climate change management(Celliers et al. 2021). In 2021, Findlater and colleagues asserted that demand-driven climate services should be contingent upon the integration of social science research(Findlater et al. 2021).

In the literature and research project outcomes, there is a positive indication of general awareness of the importance of social science and the implicit user involvement in the design and development process of climate services(Neset et al. 2024). However, there remains a persistent gap between the development of climate services and their use as a matter of practice. This requires actionable science and usable tools developed through multi-disciplinary efforts by scientists, co- producing them with decision agencies and communities(Lawrence et al. 2021).

The norms and institutions within climate science create three significant tensions when implementing climate services: an emphasis on products over processes, services based on general assumptions about demand rather than being truly demand-driven, and a narrow economic valuation of products instead of assessing improvements in decision-making. These tensions help explain why climate services often result in minimal changes in climate science despite promises of transformation. It also justifies the greater emphasis on including social system understanding in the development process(Findlater et al. 2021). A transformational approach focused on building relationships and capacities, which can both draw from and inform science, service, and practice, is essential(Jacobs and Street 2020). To ensure the effectiveness of climate services, it is essential to prioritise co-production as a foundational element in their development. Additionally, expanding the role of social sciences in both research and operational aspects is crucial(Coutinho Martins Bruno Soares and Buontempo 2019).

We suggest that the concept of climate services is mature but also requires constant re-evaluation(Jacobs and Street 2020), particularly regarding those services that are more diverse than those purely based on climate model data, and that incorporate stakeholders and users in the design process. *The proposition of this paper, and a useful evolution of the functionality of climate services is their potential to be transformed into drivers of innovation by focussing on empowering their users.* We also propose that climate services and social innovation are closely intertwined and share a reciprocal relationship. While climate services provide valuable information, tools, and resources to address climate-related challenges, social innovation brings creative solutions and approaches to tackle societal problems, including those related to climate change(Lettice and Parekh 2010). In this paper, we demonstrate how climate services development can innovate, advance means and deliver new insights to achieve and sustain a urban transition towards more resilient societies. This encompasses the creation of new insights to adapt to the new circumstances not clear yet under the uncertain and ambiguous futures. Climate services in this sense should support and drive the necessary need for transformation to sustainability.

2 CASE STUDIES ANALYSIS

To gain insight into the relationship between social innovation and climate services, we observed the production of climate services at the project level in five urban case studies. We use these observations to provide a post-hoc interpretation of how bottom-up co-production of climate services and the implementation of related actions are linked to social innovation. In each of the phases of the climate risk management process, the role of climate service development and user engagement is critical and varies (see Figure 1).

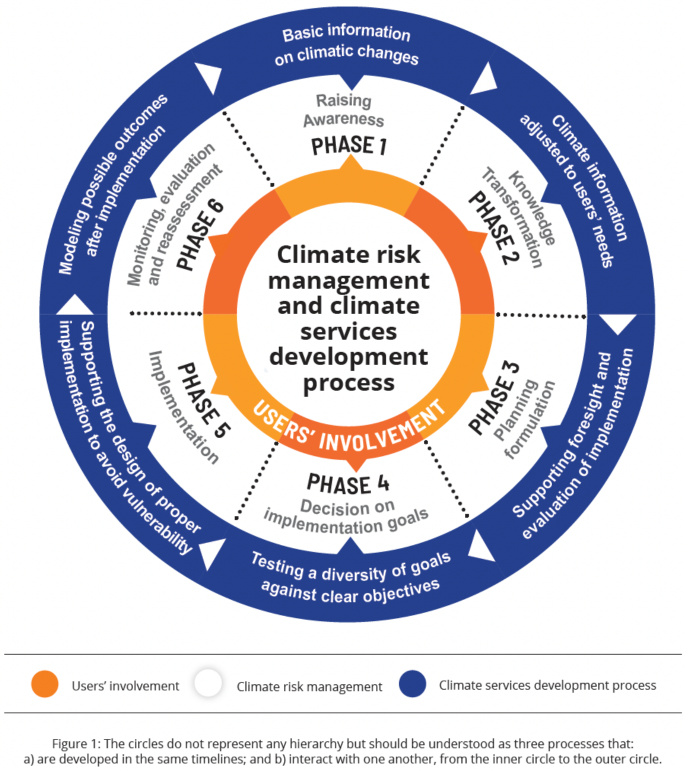

Figure 1: The levels of climate information delivery to the climate risk management process

The selection of the case studies was based on the development of climate services prototypes in five urban settings. Four of the case studies are located and active in areas in Europe and have been scaled up to a hub in Asia. The locations differ not only in terms of specific risks and physical and socio-economic conditions, but also in terms of their progress in developing and implementing adaptation measures and their progress in their climate management cycles (see Table 1). Each case study, in collaboration with identified end-users, engaged in the development of climate services for climate risk management. The case studies central focus was on a network of real-world cases, where a diverse range of stakeholders, including private sector entities, citizen groups, government agencies, and research institutions, collaborated to develop innovative solutions to pressing climate management challenges(Schütz, Heidingsfelder, and Schraudner 2019). We analyse how climate services could support users in advancing phases in their climate risk management efforts (see figure 1). We considered the complexity of the users, we captured their perceptions through participatory exercises, we co-designed business models for the service, we evaluated the compatibility of the produced service with the users and we had them test it (see Table 1 and Table 2).

The insights from Tables 1 and 2 are closely interconnected, collectively shedding light on the development and application of climate services within the context of the case studies and broader climate risk management. Table 1 focuses on the procedural aspects of the five case studies, offering a detailed timeline of their development steps. It distinguishes between the steps directly influenced by the creation of climate services (marked in grey) and those driven by pre-existing self-organisation processes (marked in white). This distinction highlights the varying degrees of integration and timing of climate services within the innovation hubs. Notably, only one case study successfully utilised a climate service developed during the research phase, prompting a deeper analysis of the climate service development process. Utilising the insights garnered from this analysis, Table 2 offers post hoc observations on the bottom-up development of climate services and its application in various stages of the climate risk management process. Through this examination of the five case studies, Table 2 demonstrates the adaptability and significance of climate services in addressing governance, management, and adaptation challenges. The findings thus underscore the necessity of a structured yet flexible framework for climate services development, as evidenced by the connections to Figure 1, which outlines the stages of the climate risk management cycle.

Table 1: Observations on climate service production in five case studies in Europe (4) and Asia (1) between 2017-2021. Grey blocks indicate where climate information was used as input.

Case study (rows) and policy process (column)	**Nijmegen, The Netherlands (Urban) River flood management**	**Valencia, Spain (Urban) Water supply**	**Eckernforde, Germany (Urban-Coastal) Coastal zone beach wrack management**	**Guadeloupe & Martinique (Small Island) Agro-ecological transition**	**Kaohsiung City, Taiwan (Urban - Island) Initiating urban adaptation**
Raising awareness: including climate risk and policy conditions	Post-1993-1995 flood event rethinking (climate, acceptance)	2000+: Identification of water supply challenges due to climate change	2010+: Growing awareness about climate change affecting beach management. Network building	2018: Green growth policy of the Regional Council of Guadeloupe: Road map for agroecological transition (under validation)	Before 2018: ICLEI Resilient Cities conferences-inspired conceptualization of climate change adaptation. 2018-2020: Capacity building and exchanges with INNOVA (hubs).
Knowledge transformation: Assessing vulnerabilities and possible interventions	2001: Room for the River plan (2006-2015)	2018+: Characterization and quantification of water supply quality vulnerabilities	2013-2019: Assessment and implementation of beach wrack management/use options (e.g. pillows, dune). POSIMA Project.	2018-2023: INRAE Antilles-Guyane defines its first thematic identifier "Agroecological transition and bioeconomy in tropical areas" in its strategic document (3SC 2018-2023), which considers the issue of adaptation of islands agriculture to climate change	2019+: National project on climate information. Taiwan Climate Change Projection Information and Adaptation Knowledge Platform (TCCIP) downscales climate data and tailor-designed climate information. Two pilots: 1) to understand and adapt to the temperature change effects on lychee farming with young farmers; 2) Urban Development and Green Building project by Public Works Department (KaoHouse 3.0).
Planing formulation: Identifying management solutions	2004-2012: Room for the River Waal iterative assessment of options (technical and architectonical)	2019+: Scoping of possible measures	2018-2019: Expert assessment of the impact of climate change on beach wrack, to address uncertainties	With Meteo-France: assessing the type, frequency and intensity of risks generated by climate change -With INRAE Antilles-Guyane: crop selection according to a vulnerability criterion (vulnerability = crop sensitivity x intensity of the climate hazard)	Taylor-designed climate information and services are co-produced for all users in Kaohsiung. A series of stakeholder events took place to co-identify with stakeholders all the possible adaptation options.
Decision on implementation goals:	2010-2016: Urban Waal River Park Decision taken, including new options developed	Future adoption of measures planned if climate scenarios are reached	2018+: Municipality adopts beach management actions	Adoption of the Strategy for Agroecological Transition in Guadeloupe	2020+: Kaohsiung will carry out socio-economic cost-benefit analysis on all identified adaptation

Proposing interventions					options, including stakeholder events for prioritization.
Implementation	2016-2018: Implementation & adaptation of technical design to social requests	Planning of implementation of measures depending on climate scenarios	2018+: Beach management, user awareness and sustainable beach wrack usage	EXPLORER project: designing crops and exploring agroecological practices reducing the vulnerability of FWI agriculture to the main threats of climate change (Karu Smart device system)	2021+: Lychee farmers: Adopt the new farming methods and/or invest in facilities to adapt to the future climate impacts. KaoHouse 3.0 implementation.
Monitoring and evaluation (and reassessment)	2018+: Evaluation and lessons learned as contribution for future projects, transfer, adaptation or upscaling in NL or abroad	(Cost-)effectiveness assessment and follow-up	Regular on-site check	MOSAICA model for testing scenarios of agriculture adaptation to climate change at the whole scale of the island (geo-localisation of the field plots)	Evaluation of both pilots.

Note to Table 2 on the users:

- In Nijmegen, the users of climate services for the different steps have changed in the process. In Step 1, basic information was requested by different administrations (e.g. water boards, municipalities) and concerned citizens. In Steps 2-5, the main users were Rijkswaterstaat and the Nijmegen Municipality, including in Step 5 also citizens who participated in the process. Step 6 users are primarily other Dutch, European and international institutions and experts, who have approached the Nijmegen example to learn from its findings and adapt the approaches and tools to their cases, e.g., Kaohsiung City in the frame of the INNOVA project.
- In Kaohsiung, the Environmental Protection Bureau of Kaohsiung coordinates cross-sectoral planning of climate change mitigation and adaptation; and is the primary user of climate services.

Table 2. Post hoc interpretation of bottom-up climate service development in five case studies in Europe and Asia, 2017-2021.

	The contribution of climates information to the case studies process	Role of users in the climate service process in the case studies
Situation including climate risk and policy conditions	Customised basic information on climatic changes	Analysing complexity of users - Awareness raising, changes in risk/relevance perception
Assessing vulnerabilities and possible interventions	Based on the customised climate information, first contributions to infusing changes into practices and first behavioural changes in the use of climate information for decision making	Problem definition & link with climate, definition of users' needs, criteria to be employed
Identify management solutions	Supporting foresight for the identification of feasible options and how these address risks	Identification of measures and management options; definition of preferences; define (spatial, financial) scenarios
Proposed interventions	Climate robustness testing as contribution to options for climate management election	Definition of priorities/weighting; Decision-making
Implementation	Support the specific implementation design to reduce vulnerability	Implementation of measures; expert advice
Monitoring and evaluation	New baseline definition, profiling of tools used	Own monitoring (e.g. cost-effectiveness of measures) & evaluation, Requests for learning and transfer of approaches and tools

The analysis of table 1 and 2 highlights the importance of understanding the procedural dynamics of climate service development and the role of user co-production. Building on the analysis of case studies, we have developed a robust framework for integrating climate services into climate risk management. This framework addresses existing identified gaps and harnesses social innovation to enhance relevance, accessibility, and impact. It prioritizes dynamic, participatory, and adaptive approaches that actively engage stakeholders across sectors and scales, extending beyond purely technical solutions.

3 DEVELOPING A FRAMEWORK FOR CLIMATE SERVICES THAT TRIGGER CHANGE

In the past, social innovation has been a trigger for enhancements and transformations that support modern human life e.g. women's suffrage. Following Griggs et al, social innovation is "any project, product, process, program, platform or policy that challenges and, over time, changes, the defining routines, resource and authority flows or beliefs of the broader social system which created the problem in the first place" (Griggs et al. 2021).

Innovation in climate services provision has the potential to trigger the transformation of society by transitioning from climate vulnerabilities towards managed risks and increased degrees of resilience (Jagannathan, Jones, and Kerr 2020; Kotova, Costa, et al. 2017). To achieve this, social innovation initiatives play a crucial role in the development of climate services. Social innovation, in this context, refers to the collaborative creation of climate services that not only drive changes in social practices but also integrate social objectives and emphasize co-production. This co-production involves active interaction between science and society, fostering a partnership that supports and encourages behavioural changes essential for effective climate action. (Edwards-Schachter and Wallace 2017; Milosevic, Gok, and Nenadic 2018).

Despite the growing need for climate-informed decision-making, the limited use of climate and weather information in adaptation policies remains a challenge. This issue stems from factors such as lack of understanding of climate information, inaccessibility of relevant data, and inappropriate formats that do not align with decision-making needs(Clifford, Travis, and Nordgren 2020; Kotova, Manez Costa, et al. 2017). o overcome these barriers, climate services must strike a balance between ontological aspects, ensuring scientifically sound knowledge, and epistemological aspects, engaging users in meaningful ways. By adopting this dual focus, climate services become a form of social innovation that integrates into routine decision-making and enables transformative change.

A shift from technological innovation to social innovation is necessary to drive societal change in climate adaptation. We propose developing climate services as design interventions that guide climate action through purposeful and transformative social innovation. Specifically, this involves targeted radical social innovation—deliberate, transformative actions addressing specific climate risks—and sustainable structural change, reshaping societal norms, decision-making, and management systems(Marques, Morgan, and Richardson 2017). These targeted interventions aim to create deep and lasting transformations, ensuring that climate services are embedded within broader societal frameworks. This means enhancing science-policy integration by ensuring that climate knowledge informs decision-making and advancing climate risk management by embedding climate services into adaptation planning.

3.1 A new framerwork for climate services

For the creation of our framework, we included two elements from theory and practice: the diffusion of (social) innovation theory(Rogers 1962),(Prihadyanti, Aziz, and Sari 2024),(Mulgan 2012), coupled with the business model canvas(Larosa and Mysiak 2019; Osterwalder and Pigneur 2010; Rubio et al. 2019). We based our selection on the analysis conducted using the only case study that successfully utilized a climate service developed during the research phase and the insights gained from it. This prompted a deeper examination of the climate service development process.

While Rogers' Theory of Diffusion of Innovations explains how new ideas, products, or practices spread and are adopted within a social system(Rogers 1962), social innovation, on the other hand, refers to the process of developing and implementing new ideas, solutions, or practices to address social needs and challenges(Mulgan 2012; Pel et al. 2020; Prihadyanti, Aziz, and Sari 2024; Westley 2010). These innovations can range from new models of service delivery to changes in policies or practices aimed at improving societal well-being in the face of climate change. The relationship between social innovation and Rogers' Theory lies in how social innovations diffuse through society. Rogers' theory provides insights into the stages and patterns of adoption that social innovations may follow. Innovations in the social sector often rely on diffusion processes to gain acceptance and achieve impact. The same is necessary for climate services use.

Furthermore, Rogers' theory emphasises the significance of communication channels, social networks and opinion leaders in the diffusion process. These elements are, in turn, fundamental components of a business model canvas. While Rogers' Innovation Diffusion Theory is concerned with the adoption of innovations within society, the Business Model Canvas is a strategic management tool that provides a structured framework for designing and refining business models to support innovation and value creation. By integrating insights from both frameworks (see Figure 2), climate services develop more effective strategies for bringing innovative products or services to users, thereby increasing the uptake of climate information and supporting evidence-based climate risk management. The approach outlined in Figure 2 is structured around two core areas for climate services development: 1) the users and 2) the value proposition.

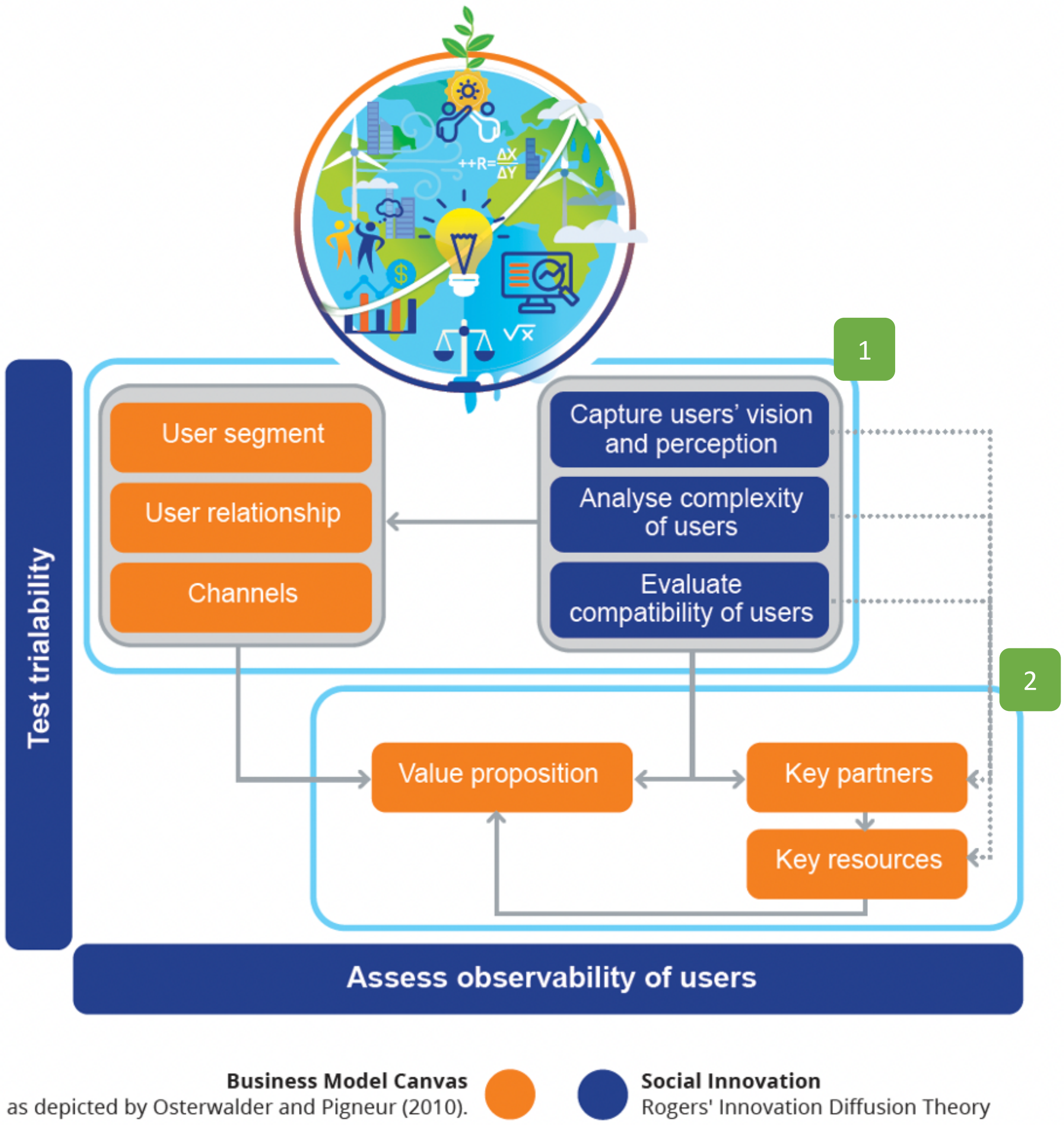

Figure 2: A new climate services framework

3.1.1 Users and innovation

Appropriate engagement with users and response to their specific needs was outlined in the Global Framework for Climate Services(C. Hewitt, Mason, and Walland 2012). Engagement with users are identified as an important element in many of the papers written about climate services(Bessembinder et al. 2019; C. D. Hewitt et al. n.d.; Kotova, Manez Costa, et al. 2017; Rubio-Martin et al. 2021; Swart et al. 2021),(Bojovic et al. 2021; M. Máñez Costa et al. 2022). However, these papers also show that the conceptual design of research is often plagued by assumptions and judgements about the behaviour of users, their role and function in the climate design process. Few papers address the actual identification of user needs for climate information and services(Hinkel et al. 2019), or measure the success of a climate service in terms of usefulness and usability for decision-making(C. D. Hewitt et al. n.d.). General approaches for co-production are not yet well established(Vincent et al. 2018).

Climate services projects showing their design are often plagued by untested assumptions and judgements about the behaviour of users, their role and function in the climate design process(M. Máñez Costa et al. 2022). This diversity in understanding users' engagement unavoidably influences the end results of climate services design processes. Even more in "self-called" climate services co-design processes, users are limited to a field of action, e.g description of the climate risk they are facing, choosing font and colours, graphical design, etc. According to Hewitt (2017)(C. D. Hewitt et al. n.d.), user engagement stretches from passive engagement, over interactive group activities to more focused relationships. In some cases users are object of surveys, interviews and workshops to engage with them in the development of a climate service(Swart et al. 2021); or they have collaborated through bi-directional meetings(Vogel, Steynor, and Manyuchi 2019). In other cases, only the usability of the climate service is tested by stakeholders (Reveco Umaña, Cristobal 2021). User interaction might also be restricted to the contact between users and research team to assess the fit-for-purpose and satisfaction (M. Máñez Costa et al. 2022). Such "fixed" models of how users feature in the design of climate services do not represent the reality of the support needed by users. "Users" or "Stakeholders" are often not well defined, and represented as a single entity or institution, a grey mass in the machinery of climate services development. However, they are an intrinsic part of the co-design process, e.g "a new species in the ecosystem of decision-finding and governance structures and processes" (Dearing 2009) for climate change adaptation.

In our framework, we re-analyse the central importance of understanding the role of users and the design goals (for users) of climate services by relating it to the Diffusion of Innovation Theory (Hemmati 2002). For doing so, we propose following steps, that consider five innovation characteristics that influence the rate of adoption for the case of weather forecast but are also fully applicable to adoption rate of climate services(Whateley, Palmer, and Brown 2015) (see figure 3): a) Analyse the complexity of users (facilitate interpretation and increase knowledge); b) Capture users' perception and support persuasion; c) Evaluate the compatibility of the user (tailored to meet operational needs) and support decisions; d) Test the trialability (ability to try without fully commit to implement it) and facilitate implementation; and e) Assess the observability of the user (the implementation can be observed by an external sources and use it) by supporting the reflexion on outcomes of the possible adaptation measure (Rogers 1962).

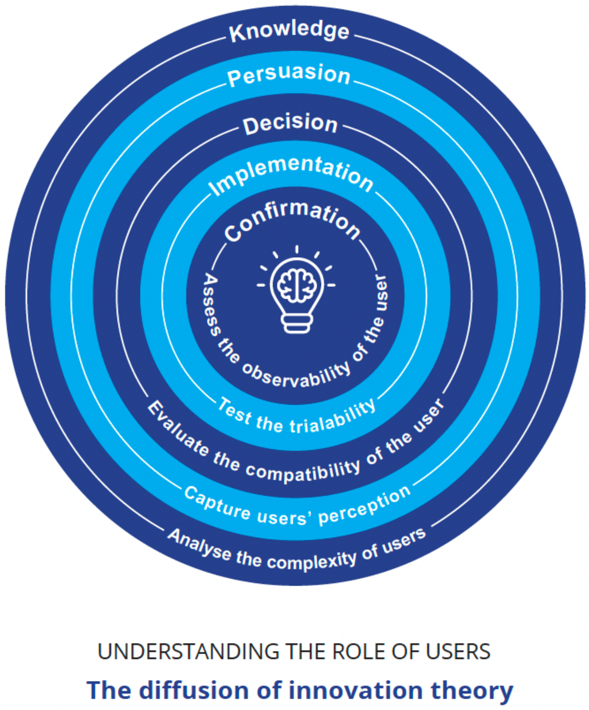

Figure 3. The diffusion of innovation theory (Rogers 1962; Whateley, Palmer, and Brown 2015)

3.1.2 Analyse the complexity of users

The literature on user involvement in science-to-policy processes highlights the presence of multiple layers of stakeholders with overlapping and often conflicting policy objectives, all with rights and entitlements to participate in decision-making.(Reed et al. 2009, 2013; Stringer et al. 2006) (Reed et al, 2009; Stringer et al, 2006)

The simplistic view of who constitute "users" is often done to reduce the complexity of engagement with multiple users, assuming that user groups have the same goal (Rogers 1962). This basic view on the grouping of users is not borne out in reality. We follow von Hippel's definition, which sees users not just as consumers, but as co-designers and creators of services, using their unique insights, needs and preferences to shape solutions(Roszkowska-Menkes 2017).

We propose a pre-step in climate service development that takes into account the diversity of users, individual goals and ambiguities, and allows for better tailoring of services. Based on this, we categorise users into four types based on their relationship to climate knowledge (see table 3) (Brink 2000). We recognise that users differ not only in their level of climate knowledge, but also in factors such as social context, access to media, age, education, cultural background, geographical location and personal experience. These factors influence how individuals perceive, understand and respond to climate-related information and challenges.(March 1978).

Table 2: User types

	Aware of climate change challenge	Informed of the available data related to the challenge	Has enough knowledge to use the available data
Preliminary knowledge	NO	NO	NO
Sufficient knowledge	YES	NO	NO
Confident knowledge	YES	YES	NO
Expert knowledge	YES	YES	YES

Legend: a) Preliminary knowledge level users: not aware of the existing climate information and also not conscious of the potential challenges that climate change might be posing into her/his decision context; b) *Sufficient knowledge level users*: aware of existing climate information but does not know how to use it to manage climate change challenges or does not agree with it (climate denier); c) *Confident knowledge level user* (data and information): aware of existing detailed climate information and knows its potential for climate service development but needs support; and d) *Expert knowledge level user* (data): aware of existing detailed climate information and knows how to use it. They could develop their own climate service

3.1.3 Capture users' perception

In the climate services literature, an increasing call for improved contextualization and co-production of climate service can be noticed (Buontempo et al. 2014; Golding, Hewitt, and Zhang 2017). It is proposed that approaches to the co-production of climate services should be context-based, pluralistic, and interactive, while ensuring that there is clarity regarding the shared goals of all parties involved. Such approaches can enhance the perceived relevance and, consequently, the utility and efficacy of climate services for the intended users.

Therefore, The subsequent phase of our framework for climate services design is employed to examine the social construction of the reality perceived by users, their decision-making processes and their perception of risk (Rubio et al. 2019). Many climate services developers exclude contemporary grey literature and evidence and users' knowledge and are, thus, prone to time lag and incompleteness related to the contextualisation of the climate services. Such actions result in an increased acceptability gap, which ultimately leads to the "valley of death" of applied research actions(María Máñez Costa, Shreve, and Carmona 2017). The term "valley of death" is used to describe a situation in which research does not progress beyond the conceptual stage and does not result in tangible, real-world implementation(Brasseur and Gallardo 2016).

The objective of our research in the five hubs was to examine the influence of place-based perceptions and knowledge of local and regional stakeholders (including representatives from civil society, authorities and political decision-makers, and enterprises) on the understanding, needs and acceptance of climate services. As evidenced by our research, a range of factors, including cultural, socio-political and economic considerations, influence how and why stakeholders assess new information, collaborate in the development of climate services and utilise these service. (Clifford, Travis, and Nordgren 2020; Catherine Vaughan and Dessai 2014)(Chabay et al. 2019).

3.1.4 Evaluate the compatibility of the user with the service.

The incorporation of user capabilities into the design of climate services can facilitate their avoidance of the "valley of death," (Jacobs and Street 2020). In accordance with Sen's capability approach, the utilisation of climate services for the purpose of adapting in a resilient manner to climate change is contingent upon the abilities of individuals and communities. Consequently, the resources available to them for the purpose of making adaptation management decisions must be considered. In addition to considering the individual capabilities of the population in question, it is also important to assess the social arrangements that they are embedded in. This entails understanding the social and institutional networks that they are part of, as well as the ways in which these networks provide them with access to additional information. Efforts are needed for avoiding the "politics of science" (Sen 1993) and supporting the figure of a user as an actor of change in detriment to the most samples of participatory processes in which citizens are embedded in normative participatory processes still dominated by science and policy (Jasanoff 1996, 2007).

In certain instances, where multiple users may be the intended beneficiaries of the climate service, it becomes necessary to consider not only the compatibility of a single user with the service, but also that of a group of them. The conflicting interests of the users, along with historical discrepancies and ambiguities between users, can result in some users failing to recognise the value of the climate service/product. This is because they perceive it to represent the interests of only one of the users. In our approach, the co-development of climate services thus concentrated on the potential synergies between the various users, who observed how their perceptions and needs were taken into account in the elaboration of the service, as captured by the concept of opportunity structure put forth by Tarrow(Tarrow 1998). This encompassed the incorporation of inclusive participatory arrangements within the delineation of the value proposition, thereby motivating incentive users to engage in collective action and facilitating the formation of synergies and common ground, with the objective of achieving a balance between the disparate interests.

In our approach implementation, the delineation of the user's capability is assessed during the climate services development face "customer segment and channels" in which we co-assessed together with the users not only their needs for a climate service to be developed but also the culture of practices and inherent knowledge arena on climate change(Reveco Umaña, Cristobal 2021).

3.1.5 Test the trialability of the climate service.

The term 'trialability' refers to the ability of users to test the functionality of a new service. It is essential that users participate in trials of the CS products at each stage of the full climate services production cycle. This is a crucial element in guaranteeing the eventual success of the utilisation of the CS. It is of significant importance for the uptake of innovative climate services, as it is only through experience that their value can be fully appreciated. The ability to trial new products or services is a crucial factor in facilitating the adoption of innovation.

Trialability in our framework implementation is embedded in the process of creation of climate services in a way that the participation of users did not come at the service handover, but with steps in between. Trialability, in this way, was very much connected to the added value of the service in detriment of existing services (Kythreotis et al. 2019).

3.1.6 Assess the observability of the user.

The assessment of observability aims to evaluate how effectively the user's existing knowledge and understanding of climate issues can be inferred from their interaction with climate information and services. This involves analyzing the extent to which these external outputs are being utilized, understood, and integrated into decision-making processes. This is directly linked to a subsequent stage of analysis in the process, namely monitoring, which seeks to ascertain whether innovation through climate services has resulted in a different adaptation management strategy than would have been the case in the absence of the service. Alternatively, it may be the case that the service has advanced users further along the adaptation policy cycle. Furthermore, observability can be conducted as an ex-post analysis.

A key point in our framework implementation is evaluating usage patterns, gathering feedback, and analyzing impacts to refine their strategies to better support users in adapting to climate challenges. This process ultimately contributed to building more resilient decisions and systems capable of responding to the impacts of climate change (see Rubio-Martin et al.(Rubio-Martin et al. 2023)).

3.2 Including business model canvas components

As represented in Figure 2, we propose to combine the diffusion of innovation with a business model to create adaptable climate services. The business model is likened to a 'recipe' that can be tailored to specific needs, although replicability should not be seen as a one-size-fits-all solution(C Vaughan et al. 2016). Each new iteration is adapted to the unique conditions of the users. Innovation is an open process that encourages new participants to contribute to and enhance the initial development (Evans et al. 2017; Ranerup, Henriksen, and Hedman 2016).

The main aim of the use of business models in this context is to increase the practice of innovative climate services. Cognitively, once a user's threshold is reached by the adoption of using climate services as a practice for supporting climate risk management design, the adoption threshold for new demands for climate services will be lower (Larosa and Mysiak 2019; Rosenstock et al. 2020). We took advantage of the well-known value proposition canvas because it facilitated understanding, communication and sharing the climate service that was developed (Osterwalder, Pigneur, and Tucci 2005). The traditional steps of Osterwalder and Pigneur depicted in figure 2 are defined segments of action for building a value proposition. They involve actions around: 1) developing the business infrastructure (composed by key activities, key partners and key resources); 2) creating the value (what distinguish this form others); 3) the customers (which segment of user, what channels to be used to deliver the service and which kind of relationship will be established with the customers); and 4) the financial resources (including the costs of creating the business and the revenue stream).

3.2.1 Focus on value proposition.

The value proposition begins by generating enabling conditions to facilitate the sustainable adoption of the climate service and close the previously mention usability and acceptability gap.

The value proposition should describe how the climate service or product helps improving the actual climate risk management situation. Strategic partners, including the user, will feed the climate services development with additional knowledge. They might belong to other climate services developers, government or non-governmental actors. The list of key partners will be enhanced with partners within and outside the user' network, depending on the needs of the user. Together with the chosen partners, key activities can be defined as the actions needed to shape, combine or process the key resources in order to fulfil the needs and expectations of the users expressed in the value proposition.

Additionally, the value proposition also lives from the resources necessary to finalise the completion of the climate service. The value proposition is key to the acceptance of the climate service. There have been many investments in the private and public sector that have failed to stimulate long-term effects in climate risk management. "Decision-makers have continued the all-too-familiar pattern of looking to the sky to inform their risk-management processes" (von Hippel 2001), instead of going to the roots of the management design and involved the affected people.

4 DISCUSSION

The adoption of climate services mirrors the evolution of other technological or innovative practices, such as weather forecasting. This process unfolds dynamically over time and within social systems, with a critical milestone often referred to as the "tipping point"—the moment when a trend gains widespread acceptance and disseminates rapidly across a population. Achieving this tipping point necessitates addressing the twin challenges of usability and acceptability, which are vital for integrating climate services effectively into climate risk management.

When examining the climate risk management implementation cycle (see Figure 1), opportunities for enhancing its effectiveness by incorporating novel concepts into the design of climate services are identified. However, this does not imply that climate services should replace existing practices. Instead, the objective is for climate services to complement and strengthen current frameworks by addressing gaps in adaptation strategies. A fundamental aspect of this integration is the understanding of the unique contexts in which climate services can facilitate innovation while aligning with established processes.

In the context of climate services, innovation entails more than mere incremental improvements; it necessitates a transformative approach that disrupts conventional practices and fosters novel decision-making paradigms. Discontinuous innovation, as conceptualised by Brooks(Brooks 2013), is particularly relevant in this context. This approach involves the development of entirely new methodologies that fundamentally alter the manner in which users interact with climate information. By fostering behavioural change and enhancing the climate risk management cycle, innovation drives the evolution of science-based services into powerful tools for adaptation and resilience.

The present study has developed a co-design process with the aim of operationalising the roles and responsibilities of society in the co-production of climate services. This participatory framework emphasised user empowerment, transforming climate services into "change-drivers" that bridge the gap between data provision and actionable insights. A notable finding emerged from the analysis of a case study, which showcased the practical implementation of a co-designed climate service, underscoring the potential for this approach to achieve substantial impact.

The relationship between climate services and social innovation is intricate and multifaceted. Climate services, in this context, are defined as the provision of data, tools and resources that are designed to address challenges related to climate change. In contrast, social innovation can be understood as the process of incorporating creativity and inclusivity into these solutions, with the objective of ensuring that they align with the needs of society as a whole. The integration of social innovation into the design process of climate services has been shown to enhance their accessibility, acceptability, and impact as demontrasted in the case study of Valencia.

The present approach underscores the necessity of designing climate services with the recipients in mind, as opposed to the producers. This user-centric approach ensures that climate services extend beyond mere data dissemination to encompass comprehensive support for risk assessment and adaptation decision-making. Furthermore, the integration of co-design processes empowers users, thereby transforming them into active participants who shape and refine these services.

The results of our study underscore the value of this approach, revealing new pathways for social innovation and timely interventions. By prioritizing reflection, informed decision-making, and user engagement, climate services can assist societies in navigating the intricacies of climate change and constructing a more sustainable future. In doing so, they move beyond their traditional role as data providers to become key enablers of social and environmental transformation. This ensures that climate services are not merely technical tools, but dynamic instruments co-created with users to foster meaningful interaction and real-world application. By establishing a connection between scientific expertise and practical usability, climate services have the potential to overcome the limitations of conventional frameworks.

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6 OPEN RESEARCH

All information presented in the paper are derived from non-personal sources and do not involve the collection of data from individual participants. No data were generated for this work.

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