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Reframing climate services to support municipal and regional planning

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ABSTRACT

Climate services were initially established with the aim to make the vast amount of climate data, projections and other climate science output publicly available to support the development of responses to society's vulnerability to climate change. In Europe embraced the concept was not only embraced to provide access to scientific knowledge and reduce vulnerability, but also as an opportunity to promote innovation, business opportunities and employment, highlighting the importance of involving users in developing climate services. However, not only differences in knowledge and skills, but also in framing of climate risks and information needs, pose a serious gap between suppliers and users of climate information, sometimes called the "valley of death". Focusing on urban and rural development at the regional and local level as key areas of application for climate services, the paper characterizes this valley of death and suggests options to bridge the gap. We suggest that reframing of the concept of climate services can help expand their applications and effectiveness, taking local non-climate challenges, opportunities and narratives into account. We provide examples from the European ERA4CS project INNOVA. The current focus of climate service development is very much on digital forms of climate change information. While this may provide a useful "back office" function, active brokerage and mediated transfer of knowledge between public and private actors, face-to-face collaboration between providers and clients ("front office"), and integration of social, economic and non-climate environmental challenges with climate risks can help bridging the "valley of death".

Practical implications

- After the initial development of climate services in several countries in the last decades of the 20th century and their formal international establishment in 2009 by WMO, climate service providers are struggling to increase their uptake and market development. The "valley of death" (framed in climate services as the divide between climate science and decision-makers, and in innovation literature as the gap between basic research and commercialization of a new product) is an important barrier to cross.
- The European Roadmap on Climate Services (2015) has three goals: making climate data more easily accessible, decreasing vulnerability to climate risks, and enhancing a thriving climate services business community. Taking an innovation perspective, the project INNOVA, on which the current paper is based, provides practical insight to achieving the latter two objectives, and thereby bridging the valley of death.
- The project focused on climate services for (peri-)urban areas in five "innovation hubs" in different regions in Europe and beyond. Each of the hubs has unique physical and socio-economic characteristics and different local climate risks: Valencia in Spain, Nijmegen in The Netherlands, Kiel Bay in Germany, the French West Indies, and Kaohsiung in Taiwan. The key questions are related to the information needs to

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enhance local resilience in these areas, the characteristics of the process to provide information or climate services, and the business case for doing so.
- Systematic interactions between climate change experts from different disciplines over a three-year period, together with representatives from different stakeholder organizations in the hubs, resulted in several insights, which augment or complement findings in the literature. Four key highlights are: recognition of the importance of local narratives and culture, language and challenges; attention to the design of interaction between clients and providers; understanding of the knowledge, skills, roles and responsibilities of providers and clients; and integrating climate risks with a broader range of non-climate policy themes. These key insights are succinctly detailed below.
- Firstly, addressing climate risks in local and regional spatial planning is part of a diversity of other socio-economic and environmental challenges. In all project hubs local narratives and culture, language and terminology associated with these challenges were found to be important to understand which climate information is needed and how it should be framed and produced in order to integrate climate risk management effectively into the broader development process. Climate service providers should recognise the importance and the diverse and dynamic nature of these local narratives as well as the culture in which they are embedded and from which they emerged.
- Secondly it should be recognized that the often-used, single-loop stepwise "adaptation management cycle" may be useful as a stylized framework, but in practice the situation is more complex. Different user groups are at different stages of this cycle, have different goals, perceptions, knowledge and skills, and the actual risk management process is much fuzzier than the simple theoretical framework suggests. In practice, climate service demand and supply can only be developed in an interactive and iterative co-creation process to define the needs and fit-for-purpose solutions.
- A third important practical implication is that different types of knowledge, skills, roles and responsibilities should be recognized when developing climate services. In some instances, users may have limited scientific knowledge and technical skills to understand and use particular types of climate information. They may initially be limited in their ability to articulate their specific demands for information services. In contrast, an over-reliance on digital, quantitative means of communicating information is a risk for climate service providers. Users may be better served by qualitative and iterative ways of communication, something for which many current climate service providers are not well-equipped.
- Fourthly, it should be recognized that climate risk management very often comes on top of, or has to be integrated with many non-climate objectives. Climate service users usually have multiple responsibilities beyond climate risk management, such as to provide housing, maintain transport infrastructure, ensure health care, stimulate employment in priority sectors or enhance urban greening. To illustrate this in the project hubs, climate services had to be connected to water management for agriculture and urban water supply (Valencia), self-sufficiency of smallholder agriculture (French West Indies), beach wreck management (Kiel Bay), flood-resilient urban expansion (Nijmegen), and synergies between urban development and agriculture (Kaoshiung).
- Integration of climate change concerns into strategies with which to address these multiple goals requires system's understanding including environmental, social and economic characteristics. This may be addressed by climate service providers either by integrating socio-economic and technical, solution-oriented expertise in their organization, or by collaborating with other expert actors and data sources in those areas.
- The ambition of the European Research and Innovation Roadmap for Climate Services is to develop climate risk management and associated climate services not only by facilitating access to climate information to help making Europe more climate-resilient, but also as an engine of development and jobs. In order to reach this goal, climate service providers have to enhance their ability to develop a satisfactory and attractive climate service proposition for customers. This suggests that transdisciplinary expertise in stakeholder engagement and communication in climate services is required to better understand the historical-cultural and institutional context, and optimize relevance of the services to the clients. Only then can "science-driven and user-informed" climate services, which are useful but with often limited uptake, be developed into more effective "user-driven and science-informed" services.

Introduction

This paper focuses on the challenges and opportunities for climate services, with an emphasis on factors of failure and success of practical applications. In a mainly European context, the paper addresses the connection between climate services and ongoing urban and *peri*-urban development planning at local and regional scales. This is arguably one of the most important areas of climate services application as urban areas are key players in climate change adaptation and mitigation, partly due to a concentration of assets, people and economic activities (Cortekar et al., 2016).

In the last decades of the previous century, in several countries "climate services" were developed, evolving from observations to also include forecasts. In 2009, the WMO formally established climate services also at the international level as "scientifically based information and products that enhance users' knowledge and understanding about the impacts of climate on their decisions and actions" (WCC-3, 2009; see Zilman (2009) for an historical overview). The central theme of the third World Climate Conference was "Climate Prediction and Information for Decision Making' and envisaged "an international framework for climate services". These services intended to "link science-based climate predictions and information with the management of climate-related risks and opportunities in support of adaptation to climate variability and change in both developed and developing countries". The implementation of the ambitious framework and associated implementation plans appeared not to be easy – and as a consequence, as Kirchhoff et al. (2013) observe, "the rate and breadth of use of scientific knowledge in environmental decision making, especially related to climate variability and change, remain below expectations".

In Europe, the European Commission embraced the climate services concept from three points of view. First, climate services were intended to help making Europe less vulnerable to the impacts of a changing climate. Second, climate services could help putting the results of decades of climate change research and data collection into practical use. Third, climate services could lead to the development of a new market with opportunities for new business development and employment. The European Commission published a Roadmap on Climate Services which defines climate services as "the transformation of climate-related data — together with other relevant information — into customised products such as projections, forecasts, information, trends, economic analysis, assessments (including technology assessment), counselling on best practices, development and evaluation of solutions and any other service in relation to climate that may be of use for the society at large. As such, these services include data, information and knowledge that support adaptation, mitigation and disaster risk management" (EC, 2015)[1].

To support the implementation of this Roadmap, significant

[1] According to the Roadmap, "Climate services have the potential of becoming a supportive and flourishing market, where public and private operators provide a range of services and products that can better inform decision makers at all levels, from public administrations to business operators, when taking decisions for which the implications of a changing climate are an issue" (EC, 2015).

investments in support of climate service development have been and are being made by the European Commission, including research (Horizon 2020, Horizon Europe programmes) and information service provision (most notably through the European Union's Earth Observation Programme's Copernicus Climate Change Services- C3S). In addition, most member states are developing national climate services and fund supporting research. While the programmes above acknowledge the importance of users for the development of climate services, they tend to evolve from a supply-oriented perspective[2]. Schemes depicting the organization of climate services typically show a complex conglomerate of boxes and arrows representing different aspects of data and software tools and their connections, to be topped of (usually at the right-hand site) with one "users" box. The lead of the Copernicus C3S development at the European level was assigned to the European Centre for Medium-Range Weather Forecasts (ECMWF), an institution which aptly combines research with operational services. However, their focus (forecasting, re-analysis of climate data) arguably strengthens a science-driven approach to climate services at the Europe level. Besides, authors involved in C3S also recognize that the management of the multiple boundaries between producers and users of climate information poses a challenge (Buontempo et al., 2014). They point at co-design and more generally at co-generation of knowledge as a key to success of a new generation of climate services which would be not only scientifically credible but also salient and legitimate. They frame this challenge as the bridging of the so-called "valley of death" which they define as the divide between climate science and decision-makers (Buontempo et al., 2014)[3].

Also, the above-mentioned definition of the EU Roadmap acknowledges the importance of the user, but still puts data and tools centre-stage. The rapporteur of the expert group responsible for drafting the Roadmap expands on its intentions by suggesting that climate services have to move from "science-driven and user-informed" to "user-driven and science-informed" (Street, 2016). Although the situation is slowly changing, much of the funded R&D on climate service development initially focused on the second of the three ambitions of the Roadmap mentioned above (access to climate knowledge).

Because of a focus on improving technological and scientific capabilities, less attention has been paid to improving the fit and usability of climate services for users (Bruno Soarez et al., 2018), which however is increasingly recognized. For example, to further develop climate services from a user-perspective and complementing the European work on climate services, the Joint Programming Initiative Climate established the ERA-NET Consortium "European Research Area for Climate Services" (ERA4CS; JPI Climate, 2016), a collaboration between national research funders. The current paper builds on research and experiences from one of the ERA4CS projects, INNOVA, addressing climate services for urban and peri-urban development planning. While climate change mitigation is not excluded (cf. the EU Roadmap), the focus is on climate impacts, risk management and adaptation.

The third ambition of the Roadmap (generation of economic activities and jobs) is as yet not well developed. Adaptation is still a low priority in many vulnerable sectors, and actual climate service market development is smaller than some literature suggests (Tart et al., 2020). This is very much in line with the authors' experiences and formed the inspiration for the research project reported in this paper. Framing climate services also from a business perspective rather than only from a scientific perspective, we use the metaphor of the "valley of death": a common term in the innovation and R&D management literature to describe the gap in an innovation process between basic research and commercialization of a new product (National Research Council, 2000; Foster, 2008; Barr et al., 2009). Translating climate information for effective use in decision-making and the testing and evaluation of this process is costly and has often been unsuccessful. This can be linked to inadequate capabilities within the research teams to move into operational user-driven services, a clear framework to support the required changes and insufficient funding for this evaluation aspect of climate services. At the same time, experience is being lost with many service development projects not moving beyond the research phase. Brooks (2013) notes that resources often exist for both research and operations, which lie to either side of the valley, but that they are often failing to transform research into operational products and services. Engagement, entrepreneurship, and evaluation are the keys to innovative and transformative services that will help citizens, businesses, and governments manage climate risks (Brooks, 2013).

The main question of the INNOVA project addressed in this paper is: *How can climate services better connect with practice and not only improve access to climate knowledge and enhance climate adaptation, but also generate new economic activity and employment?* In the next section, we summarize the main goals and methods of the project and address the broader context of climate services in municipal and regional planning contexts. We then elaborate and discuss the main findings. Finally, we synthesize the information and formulate a number of conclusions and recommendations for further developments of climate services in order to enhance the user relevance of climate services, help bridging the abovementioned valley of death and developing the viable climate services markets in Europe that were originally foreseen but which are currently lagging behind the initial expectations.

Project scope, focus and method

Focus on urban and peri-urban areas

To explore the above research question, we focus on cities and their surroundings, as a continuum exposed to climate risks. Until recently, climate risks and adaptation in (peri-) urban areas have been mainly discussed in the climate, governance, social learning, and vulnerability literature. While cities have a long history of planning for extreme weather events, the urban planning and design literature started to address responses to longer-term climate change seriously only after the turn of the century, after which climate change studies appear more prominently and consistently but focusing primarily on mitigation rather than adaptation. Explanatory factors for this lag are suggested to include the lack of interdisciplinary linkages, the absence of knowledge transfer, the presence of scale conflict, and the dearth of participatory research methods (Dhar and Khirfan, 2017).

The project collaborated with partners in "innovation hubs" with a different character and in different regions. Starting with four European urban and peri-urban areas - Valencia city in Spain, Kiel Bay in Germany, Nijmegen in The Netherlands and the French West-Indies - during the project a fifth region (the city of Kaoshiung in Taiwan) was added to allow for further international comparison. Key characteristics of the 5 hubs are summarized in Box 1. All hubs generally coincide with or include major urban areas. During the development of the project

[2] E.g., a main goal of the Global Framework for Climate Services (GFCS) following WCC-3 was "to access and apply the growing array of climate prediction and information services made possible by recent and emerging developments in international climate science and technology" (WCC-3, 2009). According to regulation (EU) 377/2014, "the Climate Change service shall provide information to increase the knowledge base to support adaptation and mitigation policies. It shall in particular contribute to the provision of Essential Climate Variables (ECVs), climate analyses, projections and indicators at temporal and spatial scales relevant to adaptation and mitigation strategies for various Union's sectoral and societal benefit areas" (EC, 2014).

[3] In this context, to support the development of C3S, ECMWF is funding a number of so-called "sectoral information system" projects (including water, agriculture, energy, infrastructure, health, tourism). In these projects, representatives from various sectors are involved in defining climate service user needs with the aim to "provide sector-specific shop windows for the C3S Climate Data Store" and test C3S products and tools. However, providing opportunities for complementary commercial climate service initiatives is not a main purpose of these projects.

proposal it became clear that the large-scale nature of climate change and the connectivity of cities with the land around them led stakeholders in some hubs (e.g., West-Indies, Kiel, Valencia) to include peri-urban areas with a rural character, the urban–rural continuum, a development that was reinforced during the project's implementation. During the implementation of the project it became also clear that it is important for developing climate services for adaptation to account for the fact that planning for climate adaptation is embedded in a long history of sustainable urban planning (e.g., Roggema, 2016; see also Box 1).

Project methodology individual hubs

The methodology applied is shown in Fig. 1, which also illustrates the way the project was organized. By exploring the climate change impacts experienced by local and regional stakeholders, the project explored how climate services can make water, climate and weather inputs useful for adaptation and resilient (peri-)urban development purposes.

In a first step, data about the specific challenges in the hubs were collected via document review, meetings and interviews with public and private stakeholders[4]. This included data on the water, weather and climate-related characteristics of the bio-geographical area (e.g. storms, floods, droughts, heat waves). But equally important, and implemented in parallel, was the analysis of prominent local narratives, risk perceptions and the capacity for climate risk management: what are the vulnerabilities and risks concerning socio-cultural-economic and political factors in each hub and how do they direct and influence choices or actions of institutions and human agents (Martinez and Stelljes, 2018)? Societal path-dependencies were analysed and resulted in a better understanding of risk perception, risk management and utilization of climate services. The analysis involved methodologies from the social science and humanities such as qualitative narrative interviews, quantitative interviews, storytelling and oral history.

The use of business models for climate services were explored next. This was done in order to guide the formal development of climate services. For this, the business canvas system of Osterwalder and Peigner (2010) was used. This system is also applied by the EU's Knowledge and Innovation Communities (KICs), to propose the following components for the analysis of climate services: User Segment; Value Proposition; Distribution Channel; User Relationship; Key Resources; Key Activities; and Key Partners. In the project context, a framework was proposed for describing the business models with co-development of climate services based on these concepts. The framework comprises three steps, 1) User selection and contact, 2) Co-design of the value proposition and agreement on the users, their relationships and distribution channels, and 3) Identification of key resources, activities and partners (Rubio-Martin et al., 2018). The framework was applied and validated in all case studies by collecting and reporting information co-collected on all these elements, but emphasised the engagement with stakeholders (Rubio-Martin et al., 2020) and by describing the individual actions taken in each hub by the involved researchers. Despite its usefulness as a design framework, the selected business model framework does not aim to directly transfer popular practices and success stories within and across different initiatives. Describing the actions taken in each hub for developing their climate, it allowed researchers to communicate contextual and socio-political conditions unique to each location. Providing general prescriptions contradicts warnings on acontextual universal business strategies which neglect wider related forces around innovation (Panagiotopoulos et al., 2012).

Particularly when it comes to developing climate services for public organizations, institutional characteristics and socio-political conditions are always embedded in corresponding business models-related decisions. It should also be noted that a selection of stakeholders or users for a project of limited duration and scope may not be fully comprehensive for pragmatic reasons and may limit the diversity of potential users, and thus leads to a partial coverage of actual business opportunities. The value proposition was the first step of the co-construction of knowledge needed for co-designing a climate service. It entails the description of the service required to meet the needs of the user. In case the stakeholder requires a specific service for which the basis already exists, the climate service proposition has to define the added value offered by the customization added to the existing service in order to better meet the needs of the user. In all cases, the definition of the value proposition is reached from the interaction between the user and the climate service provider, hence the collaborative nature of climate service co-design and the associated participation and communication process. In order to guarantee competitive advantage in the climate services market, the climate service producer must provide a value proposition. Such a proposition will have to offer distinct features such as the customized experience, differentiated service or product, lower costs or added value for the society beyond the reach of an individual user. Guidelines from the project for climate service design include innovation processes in the co-design of its value proposition, accounting for the user's position in the adaptation cycle (Fig. 2), their knowledge and awareness of the climate-related problem, and the specific needs that have to be tackled by the climate service for the benefit of the user. A following analysis by the climate service provider about the relevant data, tools, processes and key stakeholders required to co-design the service was also essential for reaching an agreed value proposition for a viable climate service (Rubio Martín et al., 2020).

Knowledge exchange between hubs

Finally, the potential for upscaling the services development process was explored, focusing on knowledge brokerage instruments to increase the uptake of the lessons learned regarding climate impacts, risk management and adaptation elsewhere. In this final step, knowledge was analysed and shared among partners and innovation hub teams to assist them to make progress in translating climate services into concrete urban or peri-urban action plans. Literature review and project exchanges with users in the diverse locations provided the context for the innovation hubs. Four meetings were organised focusing on specific issues: climate services and agroecological transitions (Guadeloupe - French Antilles), integrated negotiations and policy-making processes (Nijmegen - Netherlands), climate services and raw water supply for urban demand (Valencia - Spain), and climate services and beach wrack management (Eckenförde - Germany). Knowledge held by partners in the innovation hubs and lessons learned were analysed with the aim of transnational knowledge exchange and transfer between a broader group of partners and cities. Upscaling options were explored for four target groups: cities, businesses, planning professionals, and the scientific community. Information about the hubs is made available in a popular fashion in so-called E-zines, which can be accessed online. Furthermore, project results are communicated more widely via journal papers, conference presentations, the project website and the exchange mechanism developed in the wider ERA4CS programme.

One of the key crosscutting issues that was addressed during the project's user interaction phase was the inclusion of the theory of diffuse innovation (Rogers, 1962) as a way of starting the creation of climate services from a user-oriented vision. We aimed at focusing more on the design itself and on the users' characteristics and their capacity for inducing innovation, than on the climate information needed for creating a value proposition. Additionally, we wanted to facilitate the

[4] In this paper, we use different terms for actors using climate information, dependent on the context. *Stakeholders* can be public or private actors which have a specific interest or role in the area under consideration. They can be *users* of the climate service and its products. They can also be considered as the (potential) *client* of the climate service providers. It is important to note that they are very diverse and can have different needs even for the same climate risk in the same area.

Box 1
Selected developments in the history of (peri-)urban planning.

Planning literature (De Roo and Silva, 2010) reflects shift from single fixed quantitative targets, via multiple, dependent, composite qualitative objects to the guidance of interactions in a multi stakeholder perspective and finally even fuzzy (De Roo and Silva, 2010) en complex (Timmermans et al., 2012; Roggema, 2016) planning approaches. Developments in research and practice followed this trend. Since the early seventies, architects and cities started sustainability experiments, often thematically on local problematic topics such as green zones, traffic, urban heat or air pollution. Amongst many other ideas, Tjallingii (1995) described this phase as a 'learning by doing' approach and developed a conceptual ecological approach for an integrated strategy connecting water, energy and resource streams with spatial planning and participation of a wide variety of relevant actors. Giardet (1996) developed an integrated approach to sustainable urban planning and connected last century's urban planning schools with new sustainability principles, building on a growing awareness of the overall environmental crises. After the turn of the century new diverse and uncertain challenges for sustainable urban planning emerged: such as migration, ICT developments and climate change. Relevant for this paper, a growing amount of knowledge about climate risks became available via climate services and has to be integrated in the complex transformative planning of the climate-adaptive city, using novel methods. As a consequence urban planning transformed from a relatively simple technical issue into a complex, "wicked" problem, especially for large vulnerable cities such as the project coastal cities.

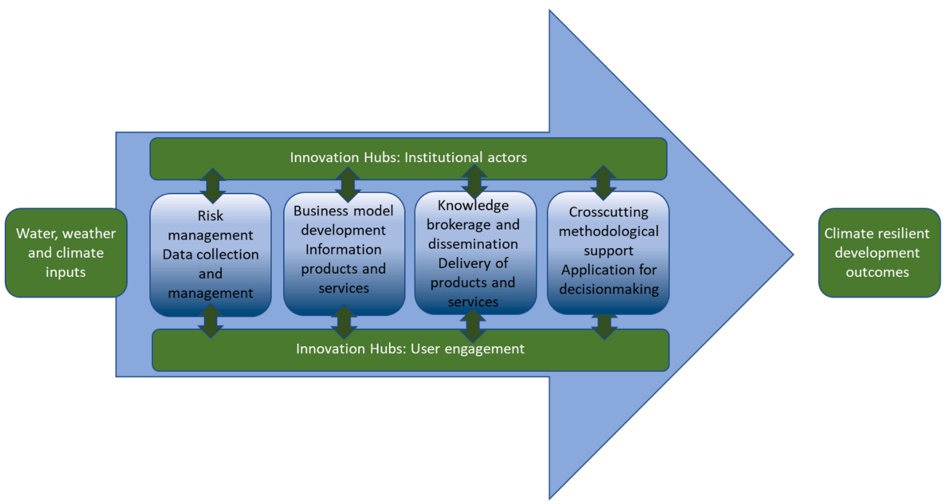

Fig. 1. The methodological approach of the ERA4CS project INNOVA.

interface between the climate information available and the users. For doing so, the project had an Advisory Board composed of users or stakeholders from the innovation hubs. They provided guidance during the full project lifetime.

Results and discussion

Table 1 summarizes the results for two main components of the activities in the project: the iterative collection and analysis of narratives and of value propositions in the different hubs. While the current paper focuses on the practical implication of the work, more details on the narratives can be found in Martinez and Stelljes (2018), while for the results on business cases we refer to Rubio Martín et al. (2018, 2020). In the final stages of the project, the project team discussed lessons learned, which resulted in a number of insights, some of which were foreseen at the onset of the project, but finetuned as a result of the project, while others were not foreseen. We present these findings below and discuss them in the context of other related literature.

Local challenges and the fuzziness of the steps of the adaptation management cycle

It was anticipated that the five hubs would be in different stages of the adaptation management cycle. As a result of interactions and exchange of knowledge and perspectives between representatives of the hubs, it became clear that even in one hub different stakeholders can be in different stages, dependent on their specific roles and perspectives (narratives), as illustrated in Fig. 2. Also, in many cases the different steps of the adaptation cycle are not always clearly separated. We have found that in practice it can be advantageous to perform a simultaneously assessment of both climate risks and management solutions in order to have the best impact on policy development. For example, climate service providers can take on a wider perspective by translating climate data to policy-relevant indicators and at the same time offering support in the design of adaptation strategies. Stakeholders very often require indicators relevant for them (like land use implications of climate risks) and support in the design of adaptation strategies, rather than (only) climatic indicators. Thus, iteratively communicating with users, climate service providers can take on a wider perspective by translating climate data to these more policy-relevant indicators and subsequently discuss the validity, consequences and implications of the information with stakeholders (e.g., Goosen et al., 2014).

The importance of an iterative climate service process design

Secondly, the nature of the participatory climate service provider-user communication process requires appropriate attention. Creating a climate service is more than just a linear communication process from science to society but rather a co-construction of the knowledge necessary to address local risks. User needs (like knowledge brokerage methods and tools) requires an iterative approach in an interactive fashion (e.g., via co-creation). It is also reasonable to expect user needs

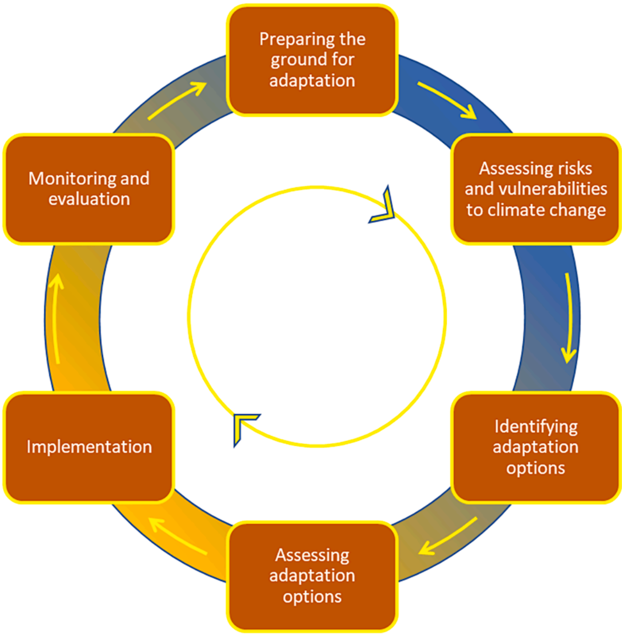

Fig. 2. The 6-phase adaptation management cycle – the emphasis of information needs changes over time from mainly climate risk data (blue) towards socio-economic information on solutions (orange). Different project hubs are in different phases, but cannot easily be positioned in the cycle because often more than one stage is addressed simultaneously and during the planning process earlier phases are revisited. Colours added by the authors to the cycle as it is commonly used in Europe (source: CLIMATE-ADAPT Climate Support Tool of the European Environment Agency, see https://climate-adapt.eea.europa.eu/knowledge/tools/adaptation-support-tool). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

to change over time as local circumstances and priorities evolve. Our experiences during the interactions with the stakeholders (climate services users) in the hubs are in line with Buontempo et al. (2018): interaction with users cannot be sporadic (e.g., at the beginning and at the end of the service development), and sufficient time should be allocated with the user to exchange knowledge and to the consequential change in definition and scope of the services. Digital climate service portals have various strengths and weaknesses and are currently an indispensable, but insufficient basis for effective climate services (Swart et al., 2017). For a climate services market to develop, providers will not only need to understand, but also adopt the terminology of their potential clients and manage expectations (Briley et al., 2015) and also understand their regulatory and cultural conditions. Additionally, the analysis of the human capital of the users as a pre-requisite for a successful climate services implementation and use, is a key consideration. This requires more intensive and novel means of collaboration and communication between users, service providers and scientists, which can be challenging for climate change researchers (Capela Lourenço et al., 2016). Which methods or tools are most suitable depends on local priorities, experiences and conditions. One useful example of an on-line guidance tool that provides access to a wide variety of tools which is constantly being updated is TANDEM, developed by the Stockholm Development Institute as component of the WeAdapt information system (see Barrott, 2020).

Recognition of different levels and types of knowledge and skills

Thirdly, the business development process identified three types of users with different knowledge and skills: *self-sufficient* users (aware of existing information and how to use it); *transitional* climate service users (aware of the existing climate risks and associated information but not yet able to use the information to the full extent to manage risks); and *potential* climate service users (not aware of the relevance of existing climate risks and associated information for their decision-making) (Rubio Martín et al., 2019). Räsänen et al. (2017) also found barriers to the use of climate information related to knowledge and skills, which can be very different between small and large municipalities. Also differences in language and framing of climate risks (cf. narratives) have to be considered (Masselink et al., 2017; Martinez and Stelljes, 2018) In this context, Krauss and von Storch (2012) argue that climate science and its public services have to critically revise their own practices, acknowledge other forms of knowledge about climate and integrate different forms of climate knowledge, especially at the regional level. This is why specific attention was given to framing and narratives in the project (Martinez and Stelljes, 2018). The interactions between research team and stakeholders in the hubs confirmed the importance of narratives and contexts and further defined them.

Connection with non-climate objectives

Fourthly, the relative importance of climate risks for (peri-)urban planning varies across different situations. It can be a main driver of (peri-)urban planning, in which case their management is usually only gradually assimilated into a wider set of other existing objectives. In many such cases, e.g. in areas prone to recurrent floods, climate services can play a role in advancing responses in the disaster risk management cycle from an initial short-term focus on emergency preparedness and response towards supporting a longer-term strategy on prevention and recovery (Swart et al., 2018; Street et al., 2018; Mysiak et al., 2018). But climate risks can also be a secondary factor, e.g. as they affect (peri-) urban planning that is being developed mainly for other societal reasons. In those cases, climate change poses a new challenge additional to existing priority socio-economic or environmental risks. Climate services has to be cognisant of these differences and reflect them in the services offered. They can either connect to other (socio-economic) advisory services, or can be expanded into a broader service, encompassing development and sustainability expertise (Fig. 3). For example, in Kiel the main challenge is related to beach wrack, the change of which due to climatic changes being only one amongst many factors. In the West Indies the main challenge identified was a push for a broad agro-ecological transition, which has climate-related water availability as one of many relevant factors. In Nijmegen, the initial focus on flood risk changed into a much broader urban development planning over time. In the Valencia hub water security for different sectors is the key multi-dimensional challenge, as it is determined by agriculture and drinking water demand for tourism and the local population.

This is consistent with the definition of climate services of the Roadmap for Climate Services and others, but not consistent with others that focus on climate data and information. Also Räsänen et al. (2017) identify a need for “non-climate services”, i.e. services that explain how to use information that is not directly related to climate and link climate risk management to overall risk management in municipalities. Climate services require more than just climate science - to work, it should be well understood how climate data and information fits into the broader decision-making context (Goddard, 2016). For example, the inclusion of positive, solution-oriented services (“a beckoning perspective”) can motivate clients to take climate risks into account in their (peri-) urban development plans. In this context it is important to note that “silo” approaches in urban planning have to be rethought, which requires new integrative methods and tools (Perrels et al., 2018).

Different situations can lead to different solutions. In many cases, broadening the perspective involves recognizing the importance of non-climate factors and collaborating with experts in relevant non-climate areas in the client’s organization (e.g., in large cities) or in specialized service institutions (e.g., supporting smaller municipalities). In some circumstances, the service provider may engage in-house non-climate expertise (e.g., if climate services are part of a broader menu of services

Box 2
The Innovation Hubs.

The **Valencia** hub is located in the semi-arid Mediterranean climate of Spain. This region experiences both long-term changes in the climate, as well as increasingly frequent extreme events. Periods of drought and flash floods have a negative effect on the quantity and quality of the raw water, putting urban water supply at risk. Other key sectors such as tourism and agriculture are also affected by the impact of these extreme events on water availability. Climate change is expected to exacerbate water scarcity in the region. This will further compromise agriculture which already consumes nearly 80% of the available water in the catchment (Marcos-Garcia et al., 2017; 2020). Furthermore, increasing frequency of extreme events requires a novel response from companies and institutions responsible for treating and supplying clean water to the metropolitan area of Valencia. Anticipating the impact of climate change on water availability and treatment in the region is a critical step for developing adaptation strategies for water security. The project co-designs a climate service to estimate future scenarios of water quantity and quality. This service will inform the treatment and delivery of clean water to its users, while minimizing the climate impacts on the regional economy.

The **Kiel Bay** hub surrounds the Eckernfoerde Bay and Kiel fjord on the Baltic coast of Schleswig-Holstein (Germany). The Bay is home to many smaller communities that are heavily reliant on coastal tourism for income generation, and the state capital Kiel City. The shoreline of the Bay is affected by sea-level rise, erosion and the flooding impact of heavy rains. The tourism sector is very reliant on the character of the beaches, and the experience and perception of tourists. Beach wrack is a mix of algae and seaweed that is naturally washed onto the beach. The project investigated whether this natural process is being affected by climate change, at the same time showing solutions how this material can be regarded as a resource. Furthermore, the project supports the development of a climate service in support of beach wrack management. Options include beneficial re-use for commercial purposes (pillows, nutrients), and natural infrastructure restoration (dune construction). The tourism managers also need to consider the impact of beach wrack under different climate projections and how that would influence planning of beach wrack management options such as mechanical removal of organic material in the tourist season.

The Dutch hub **Nijmegen** is part of the Covenant of Mayors/Mayors Adapt network, integrating the national Room for the River program to create greater resilience to climate with a major urban development project and many small-scale co-creation urban development efforts. In the case of Nijmegen this involved moving the Waal dike in Lent (northern part of the city) and constructing an ancillary channel in the flood plains, the so-called Spiegelwaal (Mirror Waal). This has created an island in the Waal and a unique urban river park with lots of possibilities for recreation, culture, water and nature. These developments have a long history, before the concept of climate services was developed. INNOVA evaluated the history of science-policy interactions with evolving planning concepts, scientific knowledge and innovation practices. New and better projections of river flows and flood risks could be regarded as climate services, which were increasingly integrated into the broader planning process over time as one of many inputs, also characterized by the development of a positive vision of the long-term, resilient development of the expanding urban area, taking the varied perspectives of a wide range of stakeholders into account.

French West Indies: due to the inherently small land area of small island states, the local economy of Guadeloupe and Martinique (and their capitals Point-à-Pitre and Fort-de-France) is subject to serious economic loss due to natural hazards such as earthquakes and extreme climate events. The islands are considered to be the 5th worldwide hot spot of biodiversity and also vulnerable to global change. Similar to other islands in the Caribbean, agriculture is an important contributor to GDP. In Guadeloupe the sector must also adapt to the impact of climate change such as decreased rains, severe flash floods, droughts and increasing temperatures. The French West-Indies has an agenda for pursuing an agro-ecological transition. The project developed climate services to support the transition from commercial crops (sugar cane and bananas) to a more climate-resilient diversity of fresh produce with the intention of making the island mostly self-sufficient in the production of vegetables.

Hub Kaohsiung is a coastal and port city in southern Taiwan with a population of 2.77 million. The densely populated city suffers rising temperature and extreme weather events such as typhoons, events exacerbated by climate change. Consequences are damage of infrastructure and industrial facilities, problems with environmental hygiene and declined agricultural and fisheries production. To cope with these problems, a wide range of measures has already been taken. Having multiple remaining challenges in the era of climate change, Kaohsiung City aims to develop integrated climate change mitigation and adaptation policy to tackle climate stressors and impacts. The project supports the creation of climate services for urban wetlands to avoid heat island effects.

such as in a major consultancy firm) or employ non-climate experts (e.g., if a climate service provider decides to broaden its portfolio). Embedding climate service providers within a stakeholder institution may also expedite climate service development, e.g., by facilitating access to the client's expertise and relevant data, notably in larger organizations. However, because of its limited scope this was not explored in the current project. The project however suggests that there is not any preferred "one-size-fits-all" solution that would fit all circumstances (e.g., small or large, public or private providers in different countries).

Climate risk management as an engine of development and jobs

A specific question of our research was if climate services can lead to new economic activities and employment. The service provided should have real value for the clients (Vaughan and Dessai, 2014), which requires a well-designed business case. The importance of financial considerations around climate services provision requires a tighter link between business and climate-related aspects (Larosa and Mysiak, 2020). While the project activities themselves did not demonstrably lead to economic growth and jobs, they did contribute to increased understanding of the factors that may stimulate or hinder such developments.

The four factors above (recognition of the importance of local narratives, language and challenges; attention to the design of the interaction process between clients and providers; understanding of the knowledge and skills of the clients; and integrating climate risks with a broader range of non-climate policy areas) were inferred, learning-by-doing, from the project team's interactions with the stakeholders but were not postulated beforehand and thus not explicitly tested. In practice, they all involve the development of "front office" capabilities to connect "back office" information with local needs. In the short term, this can generate opportunities for commercial advisory services. In the longer term, it can also lead to a boost to local economic activities from a broader point of view, such as tourism by the Mirror Waal in Nijmegen and the beach wrack management in Kiel, the agricultural development in the French West Indies and adaptation of the urban water supply system in Valencia. This finding is in line with the findings of an earlier inventory of defining characteristics of 100 projects that did not only increase climate resilience, but are also found to lead to a greater

Table 1
Key characteristics of innovation hubs considered in this paper: Local narratives and value propositions for climate services in INNOVA.

INNOVA hub	Narrative - For more detail see Martinez and Stelljes (2018), Chabay et al. (2019)	Value proposition - For more detail see Rubio Martín et al. (2018, 2020)
Valencia	Climate change is a major concern for the Valencian region, but the main risks and vulnerabilities have already been profoundly studied. The focus is now shifting towards the best adaptation strategies available for the region, with water consumption as a priority. In drought situations, restriction policies can be, maybe temporarily, applied according to the droughts plan, with serious consequences for the agricultural sector. Additionally, future climate conditions will put the urban water supply at risk in the region due to the change in water quality, requiring the performance of risk analysis and the design of contingency measures to include in the basin management plan.	To assess the effect that climate change on the future raw (untreated) water available in the Valencia region, in terms of both quality and quantity. The local partners are assisted to find the best strategies to treat and manage this resource and assess the adaptation cost. The customized design of the climate service requires the analysis of the specific geographic variables in the water cycle, rather than looking at the impact on the water resource system as a whole. The analysis performed by INNOVA is easily transferable to other cities and water-dependant sectors of the Valencia region, offering a good opportunity for the adaptation of smaller urban water supply systems to climate change.
Kiel	In Kiel people experience stronger storms, increased flooding and increased beach erosion. At the same time, a main local objective is to harvest sea grass, the removal of which also removes sand and thus accelerates erosion. A major challenge is how to integrate the management of the sea weed and other beach uses such as tourism and coastal protection. Local authorities, civil society and the tourism industry see the potential increase in beach wrack from climatic changes as an opportunity.	Developing a guidebook for beach wrack handling and sustaining attractive beaches. The guidebook presents an approach to deal with climate-related challenges and opportunities for beach use with the focus on finding effective ways to deal with beach wrack under a changing climate. The guidebook will be aimed at different users and will detail the many usages of beach wrack to create an economic advantage (soil improvement, nutrient supply, insulating material, building protective dunes) while avoiding sand loss.
Nijmegen	In The Netherlands, people are used to manage flood risks for centuries, but heat risk is new. In Nijmegen, the main challenge was not only to reduce flood risk, but how to design the areas at risk in a way that integrates multiple perspectives and offer opportunities for economic development and wellbeing of the population. Dutch tradition involves strong citizen participation.	To improve the integration of climate risks in the development and implementation of a positive vision of future urban development and share experiences with and learn from other cities. In Nijmegen, the development of the plans for the area at risk was based on flood and climate risk information before this was called "climate services". At the time, the value proposition was the development of an appealing urban development strategy rather than merely risk reduction.
French West-Indies	The people of the West-Indies have been used to live with risks of various natural hazards for a long time. Currently, a main challenge is to re-establish small agriculture increasing local self-sufficiency. This does not only require agricultural development to be resilient to climate change but also requires cultural changes reducing reliance on imports from Europe and strengthening of the creole identity.	Developing a Data Knowledge Platform (DKP) as a toolkit to support climate services design for the island of Guadeloupe and use it for developing climate services in the agricultural domain. One example of CS is to infer and display a map of agricultural parcels with their degree of vulnerability to a given hazard like drought. The DKP is also to be used for the other hubs gathering different kinds of information (data, reports, narratives, images).
Kaohsiung	As a rapidly growing tropical coastal city exposed to heatwaves and other extreme weather events like typhoons, Kaohsiung has already taken a series of measures in environmental protection (e.g. air pollution control, renewable energy) and in disaster management (e.g. flood management). However, a well-designed long-term urban development strategy integrating climate change adaptation taking climate projection into account in planning and implementation is yet missing. The next step is to use climate information collected through scientific methods, such as the downscaling of the locally used climate model, in order to co-develop diverse climate services with users. From that Kaohsiung will move towards next steps of the adaptation cycle while raising public awareness.	By using climate information to understand which risks arise from long-term climate change and how climate change adaptation can be integrated across sectors in the municipality to cope with heatwaves as well as other extreme weather events in policymaking and planning. Urban development and agriculture pilot projects were selected in Kaohsiung to identify innovations and synergies of climate services. Kaohsiung is co-developing a long-term, cost-effective, innovative and climate-resilient strategy with users.

'quality' of the project area: (i) a longer timeframe, (ii) an integrative and sustainable approach, (iii) consideration of new spatial functions, (iv) a broader spatial context, (v) participation of or co-design with multiple stakeholders, (vi) new opportunities for entrepreneurs, (vii) increased cost-effectiveness, and (viii) enhanced quality of the project area. That assessment also suggested four process-related conditions that contribute to the success of a project: early incorporation of adaptation; multi-actor collaboration and co-creation of knowledge; integrated, multifunctional and forward-looking solutions; and early political commitment (Swart et al., 2014). Especially in Europe, expectations of business opportunities for climate services are great (EC, 2015). However, the project on which this paper is based included only public research and climate service institutions and we can therefore not report specific results for private sector providers.

Synthesis and recommendations

In this paper, we argue that the current generation of climate services could be strongly improved and expanded if the so-called "valley of death" between data suppliers and the actual needs of policy makers and practitioners would be bridged through innovation of the services. As a consequence, climate services market development would be encouraged. This paper is based on applied research performed in the ERA4CS project INNOVA and the authors' experience from the delivery of climate services in other past and ongoing projects. The project brings together partners from various research and climate services institutions across Europe, active in the area of climate services. We concur with the EU Climate Service Roadmap's expectation that in addition to providing access to climate knowledge to enhance resilience to climate change, there is a potential for climate services to generate economic activity. However, this is currently only being realised very slowly, if at all. While there are also applications of climate services in support of climate risk management for specific public and private sectors or at the national level, many applications are in the area of local (e.g., municipality,

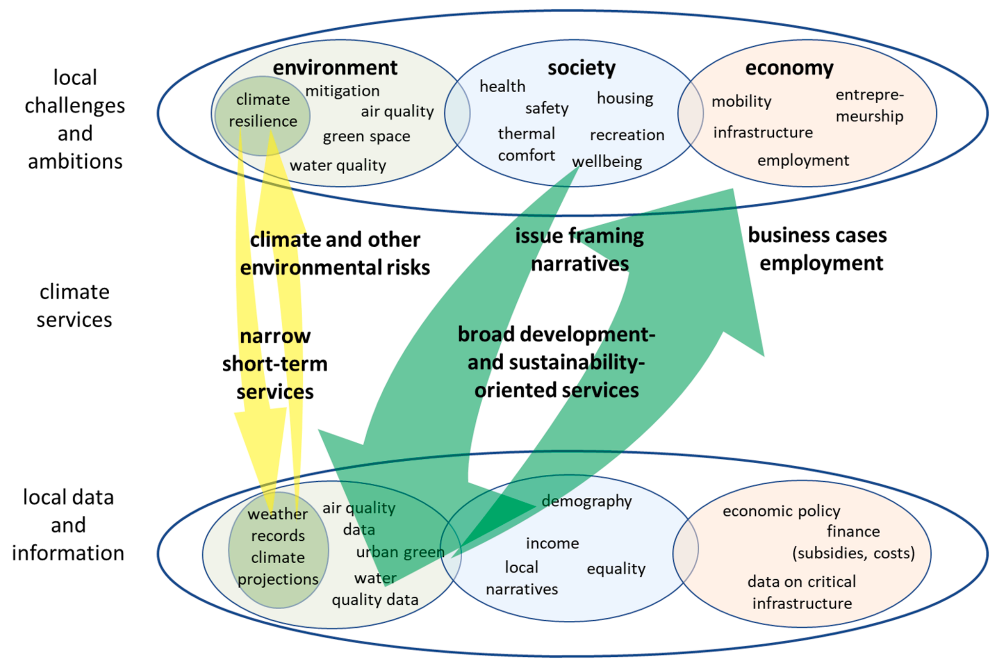

Fig. 3. From narrow short-term climate services towards broad socio-economic development and sustainability-oriented services.

neighbourhood) and regional (e.g. watershed, province) planning where climate adaptation and mitigation have to be integrated into a wider set of objectives. This paper therefore addressed the question: *How can climate services better connect with practice and not only improve access to climate knowledge and enhance climate adaptation, but also generate new economic activity and employment at the regional and local scale?*

From the project work, a number of findings emerge that provide at least part of the answer to this question. Fig. 4 synthesizes and visualizes the context and the findings of the project in the classic representation of the "valley of death" between the supply and demand side "hills", as discussed in more detail in the earlier sections. The Figure can be regarded as a graphical abstract of the paper. The top axis reflects the above-mentioned adaptation cycle, the bottom axis the themes from the scientific sources of climate services (supply) to the practical applications (use). The height of the two hills represents the magnitude of the input (left: R&D investments) and of the output with the associated key actors (right: applications, market), respectively. The green text bridging the valley summarizes our key recommendations.

Like noted elsewhere (EC, 2015; Swart et al., 2017), climate services depend on the specific situation where they are applied, as illustrated in the cases (Box 2). There is no such thing as the one generic "user" that features in many climate services box-and-arrow schemes – there are different actors with different aims, framing, roles, knowledge level, skills and questions, which change over time. For example, process and content of climate services depend on the progress made in the adaptation management cycle by municipal or regional policy makers and/or other stakeholders, a cycle which is gone through in an iterative manner, sometimes returning to earlier phases. This requires repeated, iterative interactions between the service providers and their clients in a continuous learning-by-doing and improvement process of climate services supporting adaptation planning and implementation. This role can be performed by public or private boundary workers, which could be regarded as a "front office" using data and other information from the "back office" composed of data and other information made accessible

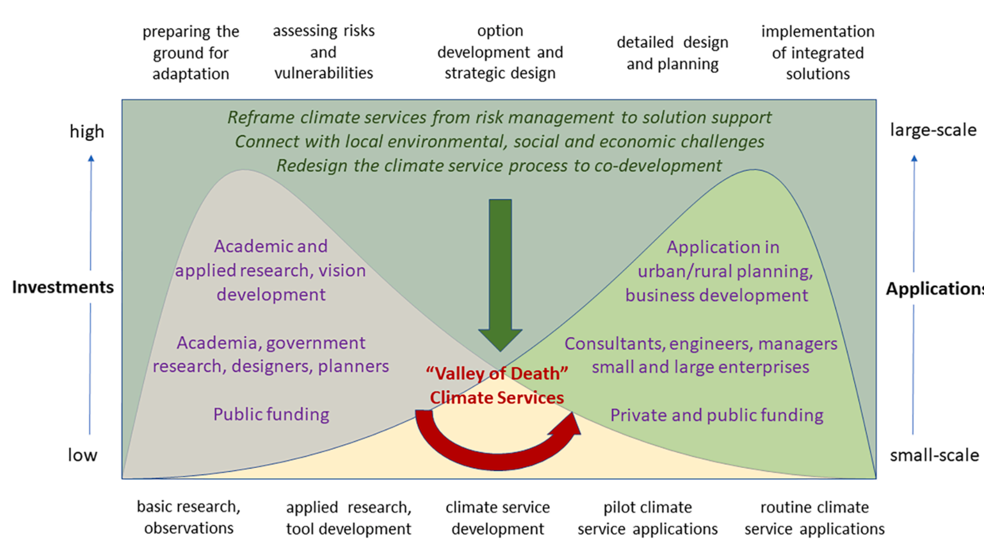

Fig. 4. Bridging the valley of death between climate knowledge supply and climate service demand.

through websites maintained by mostly publicly funded (hydro-)meteorological or academic institutions. One example of an institution with front office capabilities is the partly publicly funded Climate Adaptation Services foundation in The Netherlands which builds on – and collaborates with - climate data from mostly publicly funded ("back-office") institutions such as the Royal Netherlands Meteorological Institute (KNMI, climate data) and Deltares (flood risk data). Others include several small private consultancies across Europe.

Climate service needs in municipal or regional planning (spatial planning, infrastructure development, sectoral policy) can be either primarily driven by the need to address urgent climate risks or, alternatively, by adding climate risk management to planning activities that are driven primary by other (socio-economic, environmental) challenges, also seizing climate-related opportunities. In the former case, non-climate factors will usually be integrated during the process of designing and implementing climate risk management policies or projects. For climate service providers, it is important to understand the local cultural and socio-economic context that influences climate risk management: even climate-driven service needs require complementary information, because socio-economic and cultural aspects of vulnerability to climate risks should be accounted for. In the latter case, in which climate risks come on top of other challenges, climate factors are not primary drivers but are added to other socio-economic and environmental factors later during the design and implementation phase. In both cases, either the climate services offered should incorporate socio-economic and non-climate information, or those offering the services should be able to cooperate very closely with other service or information providers.

The analysis in the project hubs clearly revealed that the role of climate risks and choice of solutions in (peri-)urban planning - and thus climate service needs – are both influenced by locally dominant societal or political narratives (Chabay et al., 2019; Martinez and Stelljes, 2018), institutional history and culture (e.g., emphasis on hard, green or soft measures; relative importance of climate as compared to other challenges) and the associated value proposition (Rubio Martín et al., 2019). Climate service providers should at least be cognizant about this, and either connect with separate advisors in these other areas, or include the required expertise within their own organisation. Thus far, the climate services as currently being developed by institutions like the EU Copernicus programme, national meteorological services and scientific institutions, continue to focus mainly on providing access to climate data – mainly through digital means - to people with a high level of technical skills (scientists and, to some extent, intermediary advisors) rather than to inform policy makers and practitioners directly, in particular at the municipal and regional level. While these institutions also work on agreed and transparent QA/QC procedures and standards for their data systems and tools, this is not yet the case for the intermediary work between suppliers and users. This may be an issue for future work, e.g. in the context of standardization organisations such as ISO and CEN/CENELEC which since 2014 work on standards for adaptation to climate change.

What does this tell us about the "valley of death" between (mostly publicly) available climate data and other knowledge on one side (under the left curve of Fig. 4) and the timely and effective application of that information in the planning process of public and private stakeholders at risk of climate change (under the right curve of Fig. 4)? Our findings confirm those of other research (e.g., Giordano et al., 2020): the climate services market is still quite immature, value chains are often still underdeveloped and public providers with strong roots in upstream climate services attempt to reach downstream users without properly contemplated business models to do so. This is in line with our above observation that the emphasis in climate service development is on back-office functionalities rather than front-office capabilities. Which are the issues that have to be addressed to remediate this situation?

We identify the following determinants: (i) a sometimes wide divergence of technical and scientific skills between providers and stakeholders; (ii) a failure of climate service providers to recognize not only the importance but also the diverse and dynamic nature of local challenges and narratives other than climate risks; (iii) overreliance on digital, quantitative means of communicating information; and as a consequence (iv) inability to develop a satisfactory and attractive climate service proposition for customers. These findings mirror those of Portera and Dessai (2017), who note that climate scientists involved in climate service work often struggle to respond to users other than a small cadre of actors like themselves. They suggest that these climate scientists need broader social support from other experts as well as institutional goals geared towards a broader set of users if they are to successfully co-produce climate knowledge (Portera and Dessai, 2017). Our project confirms that social scientists and transdisciplinary science experts can play a useful role.

The relevance of climate services for policy and practice should be improved to help developing a vibrant mix of climate service institutions. Currently, the emphasis of climate service development lies on further optimizing the quantity and quality of databases and tools in the "back offices". This is valuable and should continue as climate, climate impacts, digital and other natural sciences and technology evolve. But it will not lead to improved and wider applications of climate services if not accompanied by the development of "front office" capabilities for enhanced boundary arrangements between climate data providers and societal stakeholders (see also Briley et al., 2015; Swart et al., 2017; Fig. 4):

a. *Reframe climate services* from risk management to solution support by integrating socio-economic and technical, solution-oriented information in the service, or collaborate with expert actors and data sources in those areas,
b. *Connect with local challenges* by strengthening the ability to advise on climate issues that are most relevant for municipalities, i.e. extreme events at local and regional level, properly considering the associated large uncertainties, and
c. *Redesign the climate service process* by involving expertise in stakeholder engagement, knowledge brokerage and communication to better understand the historical-cultural and institutional context of the diversity of users and optimize user relevance of the services provided by their co-development.

Finally, because of the factors discussed above, generation of business and associated employment, as hoped for not only in the EU Roadmap but also in the INNOVA project, lags behind what would be possible and desirable, considering the urgency of climate risks and the opportunities that exist. In order to realise this potential, existing and new climate service providers should further develop the above mentioned "front office capabilities" in order to expand their business. Our work suggests that climate services have the potential to stimulate a much larger set of economic activities and jobs beyond the consulting community by promoting a long-term positive vision on climate-resilient local or regional development and contributing to its implementation, with new opportunities in areas such as urban expansion and renewal, tourism and agriculture.

Because these opportunities do not appear to have really materialized yet since the introduction of climate services, it is recommended to test the above findings in future research. The research reported about in this paper with five different cases provided some answers and enabled formulating useful recommendations, but does not give definite and comprehensive answers on how to optimize climate services and develop a market in different contexts. Therefore, in addition to research to improve the understanding of climate change, complementary future research to corroborate the above findings and recommendations for practical application will be essential for the relevance and upscaling of climate services. Future research and development would explicitly address the current and potential future role of private sector providers, which have been poorly represented in past and current climate services

R&D programmes.

CRediT authorship contribution statement

Rob Swart: Conceptualization, Writing - original draft. **Louis Celliers:** Writing - review & editing. **Martine Collard:** Writing - review & editing. **Alberto Garcia Prats:** Writing - review & editing. **Jo-Ting Huang-Lachmann:** Writing - review & editing. **Ferran Llario Sempere:** Writing - review & editing. **Fokke de Jong:** Writing - review & editing. **María Máñez Costa:** Writing - review & editing, Conceptualization. **Grit Martinez:** Writing - review & editing. **Manuel Pulido Velazquez:** Writing - review & editing. **Adrià Rubio Martín:** Writing - review & editing. **Wilfried Segretier:** Writing - review & editing. **Erick Stattner:** Writing - review & editing. **Wim Timmermans:** Writing - review & editing.

Declaration of Competing Interest

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

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