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Review article

Upscaling of climate services – What is it? A literature review

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ABSTRACT

Translating climate data and information for use in real-world applications often involves the development of climate service prototypes within the constraints of pilot or demonstration projects. However, these services rarely make the transition from prototype to fully-fledged, transferrable and/or repeatable climate services – that is, there are problems with upscaling them beyond the pilot/demonstrator phase.

In this paper we are using the mainstream understanding of the three main types of upscaling: reaching many (horizontal), enhancing the enabling environment (vertical), and expanding the product or service's features (functional). Through a review of the general upscaling literature, coupled with focused interviews with weather/climate services experts, we found that there are common barriers to, and enablers for, successful upscaling – many of which apply to the specific case of upscaling climate services. Barriers include problems with leadership (e.g. the absence of a long-term vision and/or strategy for upscaling); limited funding or lack of a business model for the service at scale; issues with the enabling environment for upscaling (e.g. poor policy context, inadequate governance systems); and poor user engagement.

Lessons learned from the literature in the context of upscaling climate services include planning for it as early as possible in the prototyping process; including a monitoring, evaluation and learning approach to inform upscaling progress; taking actions to foster and enhance the enabling environment; and searching for a balance between generic solutions and fit-for-purpose products.

1. Introduction

Climate change is already impacting the environment and our society through the occurrence of extreme weather and climate events (IPCC, 2021). Understanding these impacts and adapting to both current climate variability and future climate change is of great importance to decision makers. To support mitigation and adaptation efforts of practitioners,[2] scientists are striving to develop and provide usable and useful climate information. However, the "raw" climate data which is typically output from climate model simulations is often not directly applicable or easily relatable to the planning or resilience and adaptation decisions faced by users. Therefore, a necessary step is the translation of these data into information that can allow practitioners to include climate change impacts in their decisions – in other words, allow users to act on that information, and to integrate it into their overall decision-making frameworks, which consider more than just climate. Climate services aim to provide this translation to actionable information. A growing number and variety of climate services have emerged in recent years, supplied by a range of service providers including government institutions, non-government organizations, universities, and private companies (e.g. Cavelier et al., 2017; Hewitt and Stone, 2021; Nenkam et al., 2019; Tall et al., 2014).

Translating climate data and information to real world applications often involves development of climate service prototypes[3] in response to identified user requirements within the constraints of pilot projects (Hewitt et al., 2020b). However, such pilot projects often remain just

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[1] Present address: Resilient Analytics (A Stanley Consultants Company), 385 Interlocken Crescent, Ste 250, Broomfield, CO, 80021, USA.
[2] We have used the terms "stakeholder", "user" and "practitioner" to indicate various participants in the upscaling process in this paper. "User" and "practitioner" are utilized interchangeably. "Stakeholder" has been used as required based on the evaluated literature and can be considered to refer predominantly to people or entities who have a wider influence and are in a position of power and ability to effect change, compared to a single user. However, we recognize that users could be stakeholders, but not necessarily vice versa.
[3] Some authors use the terms "prototype" and "pilot" in similar contexts. Here, we try to maintain the distinction of a pilot project being the activity that generates a prototype.

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that: a demonstration of what the climate service could be, due to an existing tendency not to focus as much on the process of bringing these services to a wider number of users to support national adaptation, or because the services fail to be widely distributed due to being highly contextual or country-specific (e.g., capacity-building climate services, for example, various projects under the Weather and Climate Information Services for Africa [WISER] program). Thus, one of the main pitfalls often encountered by climate service developers and providers, especially by those providers (such as research institutions) working for and on behalf of governments, is the inability to bridge the gap between a pilot project and a scaled up, transferrable and/or repeatable service (Lugen, 2020).

The establishment of a Global Framework for Climate Services (GFCS) in 2009 was a key step in enabling "society to better manage the risks and opportunities arising from climate variability and change, especially for those who are most vulnerable to climate-related hazards. … [to] be done through developing and incorporating science-based climate information and prediction into planning, policy and practice." (Hewitt et al., 2012). Although the GFCS has supported the establishment of national climate services frameworks in many developing countries (Hewitt et al., 2020a) and thus facilitated to an extent the enhanced understanding of user needs and the provision of climate information to a variety of sectors, it still has not engaged essentially in contributing towards effective and sustainable 'upscaling'[4] of climate services around the world. The meanings of the term 'upscaling' are explored in Section 3.1.

Following the Paris Agreement and subsequent focus at COP26 and COP27 on the increasingly urgent need for action, government and non-government organizations, private companies, cities, and local governments are expected to consider carefully the impacts of climate change on their operations, adaptation efforts and long-term planning. More and more practitioners will therefore reach out to climate service providers for guidance and translation of the future changes of climate. To answer these needs for provision of useful and actionable science on a large scale, newly developed or existing climate services will need to be scaled up effectively and sustainably in response to the demand.

This paper is intended to provide a high-level summary of the current state of the science and expertise related to upscaling. We aim to take into consideration not only the existing expertise in provision of climate services but also to harness the abundant experiences and knowhow from a variety of other sectors that have strived to extend and expand services to many in fight of poverty, food scarcity, declining health, and wellbeing and to reach the Millennium and the Sustainable Development Goals (UN, n.d.a, UN, n.d.b). We pose the following questions:

- What does upscaling entail? – section 3.1
- What issues could prevent a pilot project from successful scaling up? – section 3.2
- What considerations need to be taken into account when assessing if a product can be upscaled? – section 3.3
- What are the challenges and opportunities that we could encounter when upscaling climate services? – sections 3.4 and 4

2. Methods

2.1. Literature review

To benefit from the existing knowledge and expertise amassed by other sectors in the area of scaling up of products, services and technologies, and to increase our understanding of what upscaling means, we reviewed about sixty articles focused on upscaling research, case studies and experiences in a variety of sectors. The articles were selected initially by applying a variety of keywords and phrases in Google Scholar, such as 'upscaling', 'upscaling of climate services', 'scaling', 'upscaling of services', to allow the focus to be maintained on 'upscaling' as a primary topic for this paper rather than on 'climate services' in general. After a starting set of articles was identified the addition of more references was done through a 'snowballing approach': each new article provided opportunities to find new studies. Literature from a variety of sectors and programs was reviewed – such as climate services for agriculture, including agricultural research for development (25 studies); climate services (nine studies); healthcare, including nutrition (nine studies); upscaling related research (six studies); development (three studies); social programs, public and urban services (three studies); natural resources management (two studies); humanitarian and disaster risk protection (one study); sustainability transition (one study); and city climate governance (one study). Many of the studies are focused on upscaling efforts taking place in developing countries since agriculture and the international development sectors have been amongst the leaders on upscaling so far, however, the majority of the lessons that can be learned are applicable to any upscaling effort around the world.

2.2. Assessment of current experiences

In addition to the reviewed literature, we also discussed topics and pitfalls of upscaling with six scientists who have either worked for years in provision of weather services (three of them), or who have had experiences in development and provision of climate services (the other three of the group) which served as a basis for the selection of participants. The participants represented three institutions, each of which with different geographic scope and with experience of providing weather and climate data, services and information. The interviews were unstructured and as mentioned involved a limited number of participants. All of the interviewees were approached with the request to share their experiences with upscaling of weather or climate services, to emphasize any barriers or important supporting conditions that have to be considered, and any lessons learned that could expand our understanding of upscaling. The experiences they shared during these interviews are summarized in section 4 and should be considered as indicative rather than fully representative of the experiences of the wide range of weather or climate services providers.

3. What is upscaling of services? What can we learn from the existing literature and the experiences of other sectors?

The process of upscaling of services, procedures, and scientific prototypes – also called "innovations" here and in the literature – has generally been a focal point of efforts and research for several sectors in the past 20 years, however, the interest in and research on this topic has grown substantially over the past five years. The health, development, and agricultural sectors have amassed experiences and understanding which could prove very useful insight into the way in which we could apply upscaling techniques to climate services. Precipitated by the needs for scaling up and the struggles experienced by many to understand how to distribute scientific innovations in new areas and under new circumstances, and how to organize, implement and sustain upscaling, researchers have developed a new scientific discipline, "scaling science". The term "scaling science" comprises two meanings: "scaling scientific research results to achieve impacts that matter, and development of a systematic, principle-based science of scaling that can increase the likelihood that innovations will benefit society" (Gargani and McLean, 2017). In this review we are benefiting from developments and research in this and several other disciplines such as network science (Hermans et al., 2017), innovation systems (Klerkx et al., 2010) and niche management (Schot and Geels, 2008).

[4] The terms "upscaling", "scaling up" and 'scaling' are used interchangeably in this paper.

Table 1
Definitions of upscaling from the literature.

Organization or meeting, reference	Year	Sector	Definition
International Institute for Environment and Development (IIED), Hartmann and Linn (2008)	2000	Natural resource management	"more quality benefits to more people over a wider geographical area more quickly, more equitably and more lastingly"
World Bank, cited in Sulaiman et al. (2018)	2003	Agriculture and development	"replication, spread, or adaptation of techniques, ideas, approaches, and concepts (the means)," and aims at achieving an "increased scale of impact (the ends)." Purpose: "to efficiently increase the socioeconomic impact from a small to a large scale of coverage."
Shanghai Conference on scaling up, cited in Hartmann and Linn (2008)	2004	Development	"Scaling up means expanding, adapting and sustaining successful policies, programs and projects in different places and over time to reach a greater number of people"
World Health Organization and ExpandNet[a] (World Health Organization, 2011)	2010	Health	"deliberate efforts to increase the impact of successfully tested pilot, demonstration or experimental projects to benefit more people and to foster policy and programme development on a lasting basis"
Climate Change, Agriculture and Food Security (CCAFS), cited in Koerner et al. (2020)	2020	Agriculture	"the set of processes required—in the context of climate variability, climate change and uncertainty about future climate conditions—to go beyond pilot projects through sustainable change (i.e. in knowledge, attitudes and skills) that can bring higher quality solutions to millions of farmers and food system actors in a fast, equitable, inclusive, and lasting manner, towards achieving the Sustainable Development Goals"

[a] ExpandNet is a global network dedicated to enhancing scientific understanding of scaling up and its practical applications, https://expandnet.net/ (Simmons et al., 2007).

3.1. Definitions and types of upscaling

Several detailed and comprehensive definitions of upscaling are found in the literature (Table 1).

Important common themes in some of these and other definitions that highlight key characteristics of the upscaling process are:

- Intention of the process (planned and well-thought out process);
- Based on successfully tested/demonstrated innovations (prototypes) and documented evidence of success;
- Focus on high quality and adaptable products/procedures (relevant, usable, legitimate and credible innovations);
- Potential for the benefits to be realisable by a larger number of people (positive results reaching more people);
- Linked to or fostering policy and institutional change (considering the enabling environment); and
- Leading to sustainable and equitable positive impact (long-lasting and inclusive impact).

All of these points have the potential to heighten the benefits/impacts of the service in question.

Considering some of these common elements, Woltering et al. (2019) emphasize that scale, sustainability and system change are the three main dimensions of upscaling, where scale is most often attainable by governments and private sector who can also sustain the upscaling process, sustainability results from a change that becomes the "new normal" supported by local actors and system change focuses on underlying structures and supporting mechanisms.

Several types of scaling up are discussed in the literature. The majority of authors recognize three main types of scaling up (Fig. 1, also see bulleted list below), however, some (Kern, 2019) also define an additional type, 'embedded' upscaling that combines horizontal, vertical and hierarchical upscaling (their hierarchical upscaling can be considered as an element of the vertical upscaling type as used in this paper). We recognize that there is a diversity and even in some cases a confusion or contradiction of the apparent meaning of the upscaling terms used in the literature. The terms upscaling, scaling up, or scaling, used interchangeably in this paper, are not meant to imply a vertical dimension of the process only; rather, they are considered umbrella terms and are understood as encompassing the two additional dimensions, i.e., horizontal and functional as well. Here are examples of the terminology encountered in the literature; see also Appendix A for additional terminology and understanding of the type of upscaling:

- **Horizontal** scaling, also called scaling out, outscaling, spread, dissemination, scaling up, expansion, transfer, replication, scaling down, meaning generally:
  - "large-scale duplication on larger areas and for more people" (Seifu et al., 2020; agriculture)
  - expanding geographically (Poudel et al., 2017; Tall et al., 2013; Wigboldus et al., 2016; agriculture)
- **Vertical** scaling, or scaling up, upscaling generally, understood as:
  - "institutional change to a conducive environment for innovations" (Seifu et al., 2020; agriculture)
  - "building infrastructure to support full scale implementation" (Greenhalgh and Papoutsi, 2019; healthcare)
  - creating the organizational and political framework needed to go to larger scale (Hartmann and Linn, 2007; development)
- **Functional** scaling (Hartmann and Linn, 2007; development), also called diagonal (Sulaiman et al., 2018; agriculture) – including additional functions, products or diversifying/updating strategy in response to changes.

In this paper we are using the mainstream understanding of the three main types of upscaling, Fig. 1, as reaching many (horizontal), enhancing the enabling environment (vertical), and expanding the product's features (functional).

As many authors state, however, upscaling never has only one dimension, be it horizontal, vertical, or other. It is a complex process which more often is a combination of at least two types, in other words "as programs scale up quantitatively [larger number] and functionally [more complexity; enhanced functionality], they typically need to scale up politically and organizationally" (Hartmann and Linn, 2008).

3.2. Why does a pilot project rarely scale successfully to transition into a sustainable service?

Starting with a well-developed research prototype is not a guarantee

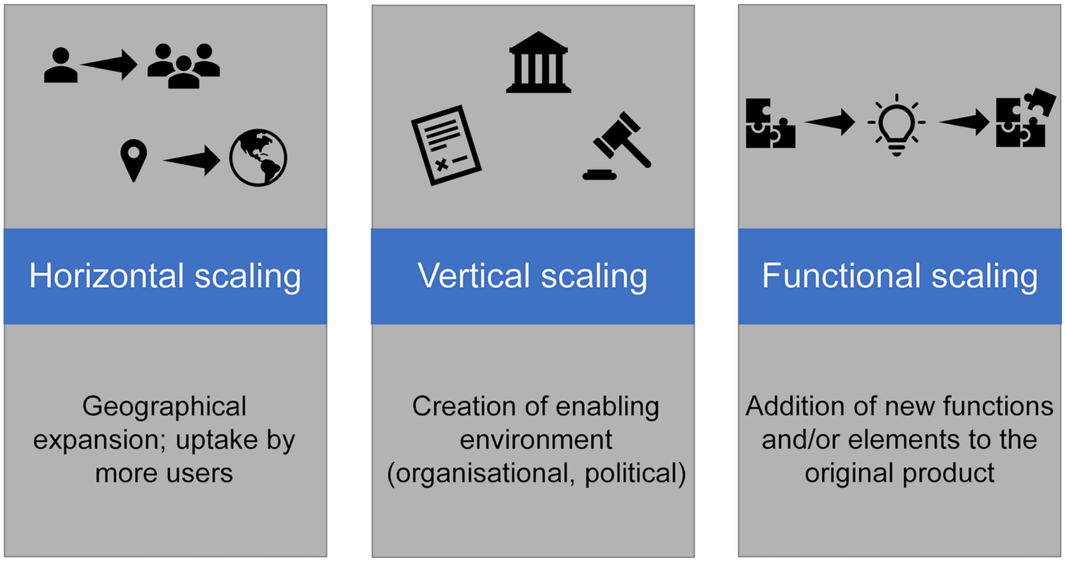

Fig. 1. Types of upscaling.

that it will be scaled effectively, successfully, and sustainably for the benefit of users. Quite often the statement found in Woltering et al. (2019) – "pilots never fail, pilots never scale" – becomes a reality. In their study the authors discuss the issues that underlie the failure of the efforts to scale a successfully developed research pilot. They highlight two major problems:

- pilot projects take place and are managed under very controlled environments
- "poor conceptual and methodological clarity on what scaling is and how it can be pursued often results in a narrow focus on reaching numbers" (Woltering et al., 2019) – that is, elements other than reaching more people are not considered.

They list several challenges for the transition from controlled environments to scale:

- **reliance on external sources** – financing is secured only for the pilot project which aims to show that the innovation works in a pilot context
- **fixed time horizons** of the pilot project, which are often quite short
- **reliance on external leadership** – using highly educated and motivated, well paid project management teams which may not collaborate effectively with local systems
- **biased collaboration** – partnerships focus on achieving the goals of the project and often are not strategic in nature; the users are the most progressive and interested participants and may not be representative of the target population
- **limited incentives to scale** – e.g., "…incentives (in pilots) emphasize direct and attributable benefits rather than systemic changes, reductions in unit cost, or transfer of responsibility to permanent players or platforms."
- **shielding from the 'real world'** – shielding from politics, regulations, market forces, and finance for various reasons; pilot projects are often tolerated by the representatives of the status quo as long as they remain pilots.
- **excessively narrow scope of pilot projects** – "lack of cross-sectoral collaboration up to highest administrative levels…"

Others highlight the challenges in capacity building, sustaining long-term partnerships, and reiterate the need for funding beyond the pilot project stage (Singh et al., 2016).

Seifu et al. (2020) cite Schot and Geels (2008) who highlight that "niche[5] experiments often fail, due to a focus on single loop learning ('How to apply a methodology') and limited involvement of regime[6] (status quo) actors. Pro-active involvement of regime actors in the methodological experiments, coupled with a dialogue with regime authorities on the vision, would create a double loop learning ('What type of methodology would be fit and acceptable in the context?')".

The WHO also indicates that pilot projects fail because the requirements of large-scale implementation are rarely taken into account at the time of pilot- or field-testing (World Health Organization, 2011). In that respect Woltering et al. emphasize that to be successful in scaling, organizations need to "design for scale from the beginning" (Woltering et al., 2019). To facilitate this process, they list a variety of scaling toolkits and frameworks that could be useful when attempting scaling of innovations, such as the Agricultural Scalability Assessment Tool (ASAT: Kohl and Foy, 2018), the Scaling Up Management Framework (SUM: Management Systems International, 2016), The Scaling Scan (Jacobs et al., 2021) and others.

Not being able to convert the outputs of pilot projects to upscaled services has been the experience of some pilot efforts focusing on delivery of climate information on seasonal scales to smallholder farmers in developing countries in Africa, South Asia, and Latin America (Kaur et al., 2015; Singh et al., 2016; Tall et al., 2014). Some of the main challenges participants in these pilot projects encountered were related to the **salience of** and **access to climate information**, its **legitimacy**, the **equity** of the upscaling process, and the **integration** of the climate services within larger programs focusing on improving the livelihood and health of smallholder farmers (Kaur et al., 2015; Tall et al., 2014). Limited **capacity to understand** and implement the provided climate information could be prevalent within the user community (Poudel et al., 2017; Tall et al., 2013), further compounding the challenges of upscaling of climate services.

In summary, learning from literature we find that there is a variety of factors that can impede or can support the transition from a pilot project

[5] Niche level – the level where the innovations develop (Wigboldus et al. 2016).

[6] Regime level – the level at which a system has reached relative stability (Wigboldus et al. 2016).

to a sustained, useful, and inclusive service that brings positive impacts to many. Many of these factors are considered in more detail below in the sections summarizing the barriers and enablers of upscaling. One of the first elements contributing to a success in scaling, however, is establishing whether the innovation is ready to be upscaled and whether the enabling environment is conducive to the upscaling process – including whether users are ready for, and receptive to, the proposed upscaled service or product.

3.3. Is an innovation ready to be scaled up?

Scaling of innovations is a complex process, one element of which is the maturity of the innovation to be scaled. A decision to move ahead towards scaling is dependent greatly on this characteristic among other factors. Below we showcase some examples of approaches to evaluate the readiness of an innovation to be upscaled.

Focusing on the 'research for development' efforts around the world Sartas et al. (2020) propose an approach named "**Scaling readiness**", intended to facilitate and support the planning and the implementation of scaling up. An important concept in this approach is the readiness of an innovation which indicates "whether an innovation has been tested and validated for the role it is intended to play in society" (Sartas et al., 2020). Modifying a technology readiness index developed by NASA and adopted by the Horizon 2020 Programme the authors propose an assessment of scaling readiness including with equal weights an innovation readiness measure (scale 0–9) and an innovation use measure (scale 0–9), for which they consider a variety of stakeholder groups using the innovation. The final scaling readiness index is obtained by multiplying the two measures. The index could provide useful information in support of prioritization of decisions when scaling innovations, highlighting readiness of the innovation to be disseminated or necessity of further development of the prototype.

Other authors also have considered evaluation of the scalability of the innovations as one of the important initial steps towards upscaling (Holcombe, 2012 – agriculture and rural development; World Health Organization, 2010 – health; Woltering et al., 2019 – development). **Scalability** represents the "potential of an innovation or change to be scaled up." (Holcombe, 2012). As mentioned above Woltering et al. (2019) provide a list of frameworks or tools to be considered when planning upscaling, some of which include elements that specifically allow for evaluation of scalability. WHO and ExpandNet (World Health Organization, 2010) in their "Nine steps for developing a scaling-up strategy" guide include a simple checklist with questions and considerations for assessing the scalability of a proposed project (see their Table 1). The "need to determine scalability" is one of the four leading principles of the framework they propose, the remaining being: "systems thinking, a focus on sustainability, and respect for gender, equity and human rights."

Finally, another good example of an approach to evaluate the scalability of an innovation is provided in Holcombe (2012) which summarizes information from a large literature review, "desk studies of 22 World Bank Development Marketplace innovative projects, field studies of three promising innovations and surveys of selected stakeholders in the innovations." The main output of this work is the proposed tool for practitioners: **Simplicity – Complexity scalability index,** which reviews simplicity factors that can support implementation of scaling up, and complexity factors that could create challenges for implementation. The tool is clear and easy to use, while at the same time being comprehensive, based on factoring in a variety of components and characteristics of the upscaling process.

3.4. Enablers of, and barriers to, upscaling

Many factors that support and contribute to sustaining the process of upscaling, called here **enablers**, are identified in the literature. A list of these factors compiled from the reviewed articles is available as Appendix B, which also details the evidence and examples directly found in the literature for each factor. All of the conditions that contribute to successful, sustainable, and effective upscaling can easily become **barriers** and insurmountable obstacles when they are not provided, developed, or cannot be afforded. Appendix C provides an analogous list for barriers to upscaling; typically, these are simply the opposite case to that for the corresponding enabler (e.g. if funding appears as an enabler then a lack thereof becomes a barrier).

The various enablers can be grouped under several overarching themes which are presented in **bold** below and are not presented in order of importance. Despite the fact that some of these factors are mentioned in the literature much more often than others, no specific criteria for ranking of these factors were found. We also refrain from ranking the enablers/barriers here due to the lack of objective criteria and lack of direct experience with upscaling which could have provided a baseline for comparison. Nonetheless, the frequency of inclusion of various factors in different studies (see Appendices B and C) could highlight to an extent the degree of their importance.

We will discuss here the enabling factors or barriers for upscaling with the intent to consider them in the order in which they feature in the process of upscaling, starting with the scalability of the innovation which needs to be based on strong evidence about usefulness and positive impacts, gathered by an organized and deliberate monitoring and evaluation process, which has been defined by a strong upscaling strategy. The upscaling process benefits from, and is greatly supported by, effective and sustained user engagement and partnerships, including supportive and influential champions, enhancing the learning and feedback which can enrich the strategy. Last but not least, effective upscaling needs to be supported throughout by a foundation of sustained financial resources and supportive enabling environment.

The enablers, along with corresponding barriers, are summarized thematically later, in Table 2.

3.4.1. Scalability and evidence of positive impact

Considerations and plans for upscaling often start to evolve, especially in a "push" (Totin et al., 2020; Wigboldus et al., 2016; Woltering et al., 2019) scaling process, after a new product, procedure, service ("the innovation") is developed within a pilot project. The innovation must have specific **characteristics** that contribute to the effectiveness and sustainability of the upscaling process. Some of these characteristics as summarized by World Health Organization (2009) are represented by the mnemonic "CORRECT": Credible, Observable, Relevant, providing Relative advantage, Easy to install and understand, Compatible, Testable. Others highlight that having strong scientific basis (Cavelier et al., 2017), local legitimacy and ability to produce benefits (Holcombe, 2012), simplicity of the innovation (Holcombe, 2012; World Health Organization, 2011), common data formats and standards, and affordability (Perrels et al., 2019) are important. Lack of some of these innovation characteristics, such as legitimacy (Tall et al., 2013; Tall et al., 2014), credibility (Hansen et al., 2019; Tran et al., 2020), reliability (Tran et al., 2020), and relevance (Blundo-Canto et al., 2021; Cavelier et al., 2017; Kaur et al., 2015; Tall et al., 2013; Tall et al., 2014; Wigboldus et al., 2016), can undermine the decision to go to scale or can lead to significant damages or maladaptation and betrayal of trust between users and providers.

One of the most important characteristics of the innovation and of the upscaling process as a whole that was explicitly emphasized by many authors is their **relevance** to the users and settings (Cavelier et al., 2017; Gillespie et al., 2015; World Health Organization, 2011; Gündel et al., 2001; Hansen et al., 2019; Kaur et al., 2015; Tran et al., 2020; Westermann et al., 2015). Adapting innovations to various and new contexts (Sulaiman et al., 2018; World Health Organization, 2009), tailoring them to local scale (Tall et al., 2014), using the local knowledge (Tall et al., 2014), adapting to "sociocultural and institutional settings" (World Health Organization, 2011), and responding to the specific user needs are considerations that need to be a fundamental element of the upscaling efforts. For the scaling process to be effective and sustainable the users' needs have to be central to the upscaling vision and strategy.

Generally, any technical characteristic of the innovation (e.g., diversity and content, format, timing, spatial coverage – Tran et al., 2020) can serve to support its wider distribution and acceptance as long as there is a proof of feasibility (World Health Organization, 2011) and successful implementation of that innovation on a small scale (Perrels et al., 2019; Tran et al., 2020; World Health Organization, 2009), as well as tangible evidence that it brings benefits and added value to users (Koerner et al., 2020). This highlights another important theme – **tested evidence**. Some authors caution "not to scale-up before needed evidence is available" (World Health Organization, 2011), which leads to one of the paradoxes of upscaling as described in the literature: "We want proof of innovation impact and scalability before deciding to scale up, but decisions on scaling up need to be made before there is adequate information" (Holcombe, 2012). Hence, **monitoring and evaluation** (M&E) are essential for the sustainability of the upscaling process and are highlighted in many papers (Bradach, 2003; Gillespie et al., 2015; Gündel et al., 2001; Hartmann and Linn, 2007; Jonasova and Cooke, 2012; Perrels et al., 2019; Sartas et al., 2020; Seifu et al., 2020; Tran et al., 2020; World Health Organization, 2011). The failure to plan, organize and perform regular, effective and timely M&E activities, especially assessments of the innovation's impacts to users (Hellin et al., 2017; Jonasova and Cooke, 2012; Koerner et al., 2020), leads to an inadequate evidence base (Poudel et al., 2017; Tanner et al., 2019) for the decision whether to go to scale or not, and also leads to lack of solid evidence (Koerner et al., 2020) to help with adapting the upscaling process as time progresses.

One important step in the initial stages of the upscaling process is the assessment of the scalability of the innovation. This means that M&E has to be considered and planned for from the very beginning (Tall et al., 2013) of the pilot project thus allowing for the necessary evidence in support or opposition of upscaling to be gathered. Furthermore, the M&E process should be "continuous, independent, dynamic" (Holcombe, 2012) and should cut across all stages of the upscaling process. This will allow at any stage – and based on testing in a variety of sociocultural and institutional settings (World Health Organization, 2011) – a decision to be made whether to continue or not, what to change and how, and whether it is still financially viable to upscale, to name some of the considerations to be taken into account.

3.4.2. *Planning and leadership*

A decision whether to go to a larger scale or not needs to be backed by a clear **vision** (Gillespie et al., 2015)**, strategy, and plan** (Holcombe, 2012; World Health Organization, 2010) for the upscaling process. Some practitioners suggest to "design and test innovations with scaling up in mind" (Simmons et al., 2007; World Health Organization, 2009). A strong "Theory of change"[7] (Bradach, 2003; Holcombe, 2012) that includes sustainability of the process (Simmons et al., 2007) as an important consideration from the very beginning is suggested in order to have an orderly and effective upscaling process. Having a systematic planning approach, however, should not lead to rigidity. Flexibility (Totin et al., 2020) and considerations of different options related to implementation of the upscaling process may be necessary as time progresses and information is accumulated through the M&E process. Finally, the importance of strong and effective **leadership** (World Health Organization, 2009) within the user, the implementing, and research organizations needs to be highlighted.

Related to the vision, strategy and planning of upscaling, the various authors list additional important challenges: low innovation readiness (Sartas et al., 2020), lack of involvement of private sector, inability to keep pace with increase in uses and users (Blundo-Canto et al., 2021), large-scale implementation not considered through the pilot project or during field-testing (World Health Organization, 2011), pilot case not being generally applicable (Gündel et al., 2001), difficulty to integrate available climate information in existing practices and workflows (Cavelier et al., 2017; Tall et al., 2014), lack of adequate attention on sustainability of practices (Poudel et al., 2017), problems of strategy and management (Bradach, 2003), and lack of strong leadership.

Furthermore, the inability to **understand** well **the system** (Woltering et al., 2019) **or process** of upscaling, or to capture the **full value chain** (Hellin et al., 2017) is a barrier explicitly brought to the foreground by many authors. Narrow focus on numbers and "poor conceptual and methodological clarity of what scaling is and how to do it" (Woltering et al., 2019) can be significant obstacles.

3.4.3. *User engagement, partnerships, and communication*

Key lessons around user engagement for upscaling climate services involve concepts that are similar to those for co-producing the services themselves (e.g. Bojovic et al., 2021; Buontempo et al., 2018). Specifically, one of the cornerstones of the upscaling strategy for climate services needs to be an effective **user engagement** approach, which involves users in a meaningful (Soares and Buontempo, 2019) and empowering way through focused relationships. Such active user engagement needs to reflect participation in decision-making related to service development and upscaling and engaged participation in evaluation and monitoring of these services, thus representing the "re-distribution of power and benefits", and the avoidance of tokenism, which according to Arnstein (1969) indicate the highest level of "citizen participation". In summary, engaging with local stakeholders from the very beginning (Woltering et al., 2019), including them in the design, production and evaluation (Hewitt et al., 2017; Tall et al., 2014; Tran et al., 2020), using participatory approaches (Gündel et al., 2001; Singh et al., 2016; Tall et al., 2014), are some of the important lessons from the various efforts to upscale innovations. Building trust, ownership (World Health Organization, 2011) and commitment (Totin et al., 2020) can be achieved when the interactions between users, project leads, and implementing organizations are effective and bi-directional (Perrels et al., 2019). Considerations of **equity** during the upscaling (Bradach, 2003; Tall et al., 2013; Tall et al., 2014; World Health Organization, 2009), recognizing the uniqueness and variety of the users, their specific economic and socio-cultural constraints, and their vulnerabilities (Tran et al., 2020) increases the fairness and inclusivity of the process.

A theme that represents an important challenge and to a great extent also relates to the equity of the provided services is the **access** (Tall et al., 2014) to climate services, information, and guidance. Such access or lack thereof could be impactful to all users and could relate to appropriate distribution channels (Hellin et al., 2017; Tran et al., 2020), timeliness of the service (Kaur et al., 2015; Tall et al., 2013), weak infrastructure for provision (Jonasova and Cooke, 2012; Tran et al., 2020), language barriers (Jonasova and Cooke, 2012; Tran et al., 2020), and cost for translation (Tran et al., 2020). It could also affect only certain groups and can be illustrated by, for example, difficulties in the provision of services to poor and remote communities (Jonasova and Cooke, 2012; Tall et al., 2013), or can relate to the literacy of users (Jonasova and Cooke, 2012; Kaur et al., 2015) thus impacting their ability to use and benefit from the services. An important barrier is the failure to appreciate and consider the complexity of the user engagement process, the time- and resource-consuming collaborative design and co-production (Hansen et al., 2019) of prototypes, and the individuality of the users. This could lead to development of products that may not be relevant and will not bring benefits to users – which is one of the main goals of upscaling. Making commitments to stakeholders without understanding their needs (Koerner et al., 2020) can be detrimental to the user-provider relationships and the credibility and reliability of the provider institution.

The efforts of going to scale will not be effective or sustainable if projects do not include a variety of stakeholders and partners that could

[7] Theory of change includes the set of actions that will produce the needed outcome using the innovation (Holcombe, 2012).

contribute resources, understanding, leadership, support, or complementary capabilities (Lambin et al., 2020). Strong **partnerships**, sustained interactions (Tall et al., 2014), concerted efforts (Simmons et al., 2007) for collaboration (Hermans et al., 2017; Perrels et al., 2019; Woltering et al., 2019) and coordination (Kaur et al., 2015; Koerner et al., 2020) could serve as catalysts (Gündel et al., 2001) of the upscaling process and could lead to more robust buy-in (Greenhalgh and Papoutsi, 2019) from the various participants. Multi-stakeholder agreement (Sartas et al., 2020; Sulaiman et al., 2018) on the roles and necessary actions to support and sustain upscaling based on aligned motivations (Lambin et al., 2020) can foster effective and strong ownership (Singh et al., 2016) of the process by a variety of participants which only strengthens further the conducive institutional environment.

Driving the upscaling process forward is especially successful when effective and persuasive **champions** (Bradach, 2003; Gillespie et al., 2015; Hermans et al., 2017; Holcombe, 2012; Jonasova and Cooke, 2012; Koerner et al., 2020; Lambin et al., 2020; Perrels et al., 2019; Singh et al., 2016; World Health Organization, 2011) from the variety of partner organizations can be identified. Strong champions can play the role of leaders and can be very influential during implementation of the innovation. The partners' or the user-provider interactions are productive when the **communication** is two-way, involves knowledge sharing (Hermans et al., 2017), capacity strengthening (Blundo-Canto et al., 2021; Hansen et al., 2019; Koerner et al., 2020; Simmons et al., 2007; Sulaiman et al., 2018; Westermann et al., 2015; World Health Organization, 2010), building of consensus (Gündel et al., 2001) and common understanding, and promotes learning (World Health Organization, 2011). **Learning** is an integral part of the upscaling process during each stage including design, development, implementation, and evaluation. Upscaling is a dynamic, multi-dimensional (Hartmann and Linn, 2008; Simmons et al., 2007), adaptive process and all of the participants could benefit greatly from any new findings provided by M&E, from new approaches inspired by local experience and knowledge (Bradach, 2003; Tall et al., 2013), and from better understanding of the complexity of the weather and/or climate processes, impacts and risks (Perrels et al., 2019; Tran et al., 2020).

Absence of partners and champions (Perrels et al., 2019), inability to sustain effective long-term partnerships and cooperation (Koerner et al., 2020) among multiple stakeholders (Singh et al., 2016), not including influential organizations in upscaling, sparse and disconnected innovation networks (Hermans et al., 2017), lack of understanding and cooperation between different stakeholder groups (Koerner et al., 2020), can all be considered barriers for an effective and successful upscaling. Related to learning, obstacles become the absence and fragmentation of knowledge (Hansen et al., 2019), limited facilitation skills (Seifu et al., 2020), and difficulty to understand current climate information and uncertainty (Cavelier et al., 2017).

Finally, the lack of **capacity** (Hansen et al., 2019; Singh et al., 2016; Smeds, 2020) to implement an innovation (World Health Organization, 2010), to work directly with users (within National Meteorological Services – Tall et al., 2013), to apply the information, in terms of human and financial resources within the relevant institutions (Poudel et al., 2017), absence of staff who can interpret climate information (Kaur et al., 2015), and lack of interactive support for users (Perrels et al., 2019) are all elements of the capacity-related barriers theme identified in many of the studies.

3.4.4. *Financial considerations*

An essential condition to initiate upscaling is to have adequate, lasting and stable (Bradach, 2003; Gillespie et al., 2015; Jonasova and Cooke, 2012) financial resources (Blundo-Canto et al., 2021; Greenhalgh and Papoutsi, 2019; World Health Organization, 2009). With regards to **financing**, authors stress the importance of "advocating for financial support beyond the pilot stage" (World Health Organization, 2011), "financial sustainability" (Gündel et al., 2001), using new and "viable business models" (Perrels et al., 2019; Tran et al., 2020), creating incentives (Hartmann and Linn, 2007; Jonasova and Cooke, 2012; Perrels et al., 2019), investments in capacity, "knowledge, technologies and human capital" (Poudel et al., 2017; Tall et al., 2014). The overall goal is to secure reliable funding (Bradach, 2003) that will support and sustain the upscaling process. Of course, lack of or limited and unstable **funding** (Kaur et al., 2015; Koerner et al., 2020; Lugen, 2020) and resources (Gündel et al., 2001; Seifu et al., 2020; World Health Organization, 2010), including absence of commitment to fund (Tanner et al., 2019), deficiency of viable resourcing models for products that will need frequent updates (Perrels et al., 2019), donor fatigue (Bradach, 2003), (difficulties) finding cost effective scaling models (Koerner et al., 2020), and no funding beyond the pilot phase (Singh et al., 2016) are all crucial limitations that can be detrimental to the scaling up.

3.4.5. *Enabling environment*

Last but not least, attention to the **institutional and enabling environment** is critical for upscaling. Regardless of the type of upscaling, the process will always benefit from political commitment and support (Blundo-Canto et al., 2021; Hartmann and Linn, 2007; World Health Organization, 2011), positive, conducive and coherent policy context (Cavelier et al., 2017; Greenhalgh and Papoutsi, 2019; Perrels et al., 2019; Poudel et al., 2017; Singh et al., 2016; Sulaiman et al., 2018; Williams et al., 2012) and sectoral reforms (World Health Organization, 2010), adequate governance structures and systems (Gillespie et al., 2015), considerations of existing economic system and enabling context, links to government policies and interventions (Totin et al., 2020), connections to national and regional frameworks for climate services (Tran et al., 2020), institutional arrangements and support (Aggarwal et al., 2018; Tall et al., 2014), to name a few of the supporting components related to the enabling environment. On the other hand, many of the definitions of upscaling highlight that the process itself can bring about system changes, can foster new policies, or institutionalization of change into routine systems (Woltering et al., 2019). Some of the pathways towards institutionalization and gaining political and institutional support and commitment are to advocate for and influence necessary changes in regulations, policies (Gündel et al., 2001; Jonasova and Cooke, 2012) and other system components (Holcombe, 2012; World Health Organization, 2011), to demonstrate the success of a project (World Health Organization, 2011), to "promote [ing] formal institutional and policy arrangements" (Hansen et al., 2019), to define clearly the competencies of different agencies participating in or supporting the scaling up (Holcombe, 2012), to integrate adaptation into "existing public and policy agendas (Williams et al., 2012), or to "promote[ing] the use of climate services and standardizing products, ratings, and quality assurance of climate services" (Perrels et al., 2019).

A large set of conditions can render the institutional and enabling environments challenging for and obstructive of the upscaling process – such as, unfavourable macro and institutional environments (Gündel et al., 2001; Hellin et al., 2017; Sulaiman et al., 2018), systems with weak capability to implement innovation and characterized by multiple pressing priorities (World Health Organization, 2010), lack of cohesiveness of the climate services community, growing number of organizations providing climate services (Hansen et al., 2019), shift in donors' priorities, changes in governments, non-governmental organizations' (NGO) funding driven by fashion, agency managers and staff moving in and out, no support for the scaling process – inertia (Hartmann and Linn, 2007), weak linkages between local and higher levels (Hermans et al., 2017), diffused decision power, complexity and demands for coordination (Holcombe, 2012), weak coordination among actors (within government agencies and between government and the private sector – Poudel et al., 2017; Tran et al., 2020), competition between agencies (Tanner et al., 2019), lack of institutional embedding, mistrust or lack of commitment among parties, lack of climate service policies for users and their needs (Perrels et al., 2019) or absence of integration of the upscaling process within larger programmes focusing on improving the livelihood and health of smallholder farmers (Kaur et al., 2015; Tall et al., 2014).

3.4.6. Other factors

Finally, some of the **miscellaneous** lessons learned regarding important contributing factors for effective upscaling were the need for longer time scales for projects (Greenhalgh and Papoutsi, 2019; World Health Organization, 2009), the necessity for research on upscaling (Simmons et al., 2007), focus on improving usability of nationally produced climate information and filling observational data gaps (Hansen et al., 2019), and considering external catalysts such as crises and natural disasters (Hartmann and Linn, 2007), for example.

Some additional issues that cannot be grouped under the themes above were put forward as impeding the process of scaling up: data availability (Hansen et al., 2019; Hellin et al., 2017), risk of acting 'in vain' (Tanner et al., 2019), climate services not considered worth the cost (Perrels et al., 2019), and decreased confidence in different elements of the climate services value chain (Tran et al., 2020).

4. Experiences of weather and climate services providers

This section summarizes information from six informal interviews with colleagues from government organizations and two universities in developed countries, who have worked for years towards provision of public weather forecasts and warnings, or climate information and services.

The interviewees echoed many of the findings summarized in the previous sections, for example:

- considering the attributes of the provided products and the co-production of climate information they mentioned the importance of relevance and usability of products, users questioning the credibility of the products, the need for co-design and co-development of climate information with practitioners, the challenges to incorporate climate information in user organizations, and the capacity and competency of users to apply the information they receive;
- engagement with users from the beginning was stated in every conversation, and the provision of opportunities for product feedback from users including a fast response from developers to any queries was specified as another important element in the process of upscaling;
- related to the enabling environment, the interviewees also discussed the lack of political support or of clarity about responsibilities of different agencies providing climate information/services, the importance of champions, the deficiencies of existing policies and regulations related to climate change adaptation, the significance of successful and effective partnerships, relationships, networks and trust, and the understanding of the value chain of climate services;
- the absence of appropriate or adequate funding was also identified as a large barrier to successful scaling up; and
- considering the link between affordability and the business model of the upscaling process an important difference between weather and climate services was highlighted, specifically that in many countries the weather services are government supported enterprises and this greatly facilitates the dissemination of information, forecasts and warnings.

The conversations with these service providers also brought forward additional insights related very particularly to scaling up of climate or weather services. These new considerations reflect the specifics of the climate services process and value chain. It was highlighted that sometimes a large variety of existing providers of climate data or information may lead to fragmentation of the climate services sector, which together with the lack of standardization or evaluation of the quality of the products may bring erosion of user trust, misuse of information or may lead to maladaptation. Performing detailed market research to elucidate

Table 2
Summary of enablers and examples of barriers of upscaling. New topics differing from the enablers' topics and related to barriers are shown in italics in boxes in the table that do not have a counterpart enabler topic.

Enablers of upscaling	Barriers to upscaling
Data provision; filling observational data gaps	Large variety of existing providers of climate data or information possibly leading to fragmentation of the CS sector, which together with the lack of standardization or evaluation of the quality of products may erode user trust, lead to information misuse and possibly result in maladaptation
Characteristics of the innovation such as credibility, provision of relative advantage and benefits, ease of installment and understanding, compatibility, ability to be tested, as well as strong scientific basis, local legitimacy, and affordability	Lack of these characteristics
Relevance of innovation	
Observability of the positive impacts the innovation brings – **tested evidence of positive impact**	Failure to plan, organize, perform regular M&E, inadequate evidence base, lack of solid evidence
Comprehensive monitoring and evaluation (M&E)	
Well-developed and focused vision, strategy, plan	Narrow focus on numbers and lack of conceptual and methodological clarity of what scaling is and how to do it, low innovation readiness, and more
	Lack of understanding the system or the process of upscaling
Strong leadership	Lack of strong leadership
Effective user engagement – user engagement has to become a continuous, long-lasting process	Failure to appreciate and consider the complexity of the user engagement process, the time and resource consuming collaborative design and co-production
Equity, inclusivity of engagement	Failure to consider the uniqueness of users
	Lack of access to services, information, guidance
Sustained and effective partnerships	Absence of partners, inability to sustain effective long-term partnerships among multiple stakeholders, and more
Champions	Absence of champions/catalysts
Communication and two-way knowledge-sharing	Absence and fragmentation of knowledge, lack of user feedback
Continuous learning	
	Lack of capacity *to implement an innovation, to apply the information*
Stable, adequate, and sustained financing	Absence or limited funding and resources, absence of commitment to fund, no funding beyond pilot phase, and more Climate services not considered worth the cost
Institutional and policy enabling environment	Unfavorable macro- and institutional environments, lack of cohesiveness of the CS community, weak coordination among actors (within government agencies and between government and the private sector), lack of CS policies for users and their needs, and more
Miscellaneous - longer time scales of projects, research on upscaling, and more	Risk of acting in vain, decreased confidence in different elements of the CS value chain

demand should be a necessary step in a pilot project developing prototype climate services which resonates with the concern expressed by Findlater et al. (2021) that "services [are] based on broad assumptions about demand rather than being demand-driven". Identifying the user needs for climate information could be most efficient when providers understand the specific decisions users are planning, which may at times even necessitate embedding of weather or climate scientists within the user organizations, thus creating effective and productive partnerships and increasing the relevance of the provided products. Thinking about the user-developer co-development and co-production activities which have been recognized as very time and resource consuming by many (Hewitt et al., 2017), would it be possible to upscale the user engagement process?

Considering the transition from pilot to delivering transferrable and/or repeatable services, the participants stressed that this is a complex undertaking that requires substantial resources and user engagement does not end there, but has to become a continuous and long-lasting process of provision of user feedback, that could help with the improvement of the products as well as support of users during application of the provided information. A challenging and complex tension exists between too generic vs tailored climate services that is not easy to navigate. Furthermore, the development and provision of weather and climate data and information entails complex and time-consuming pre-processing and production steps, including the addition of supporting metadata, development of guidance materials, and explainers of appropriate usage – which may not be taken into consideration while planning for upscaling, thus creating a barrier to the process. Finally, investment in communication, outreach and promotion of the climate services needs to become a focus of attention that could lead to a sustained and successful scaling up.

Considering this information together with that gathered from the literature in Section 3.4, Table 2 provides a summary of enablers of, and barriers to, upscaling.

5. Summary and lessons learned

Potential future needs for provision of climate services on larger scales will require mobilization of resources and well-organized efforts. To prepare effectively in response to this challenge we performed a literature review focusing on upscaling of products and services from different sectors. This review was intended to increase our understanding about the process of upscaling, and the necessary conditions and challenges that could support or prevent the successful and sustained implementation of a given service on a large scale. Existing literature indicates that upscaling is a complex, dynamical, multidimensional, and non-linear adaptive process. While there are many existing definitions of upscaling, most of them include the following characteristics: planned and intentional process, based on documented evidence of success and benefit, providing innovations with high credibility and quality, relevant to users, reaching more people and organizations, existing within or leading to supportive enabling institutional and policy environment, sustained by adequate funding, and providing long lasting, inclusive, and equitable positive impacts.

Although three major types of scaling are recognized in the literature – horizontal, vertical, and functional – many authors have stated, however, that upscaling never has only one dimension. It is a complex process which more often is a combination of at least two types, in other words "as programs scale up quantitatively [larger number] and functionally [more complexity; enhanced functionality], they typically need to scale up politically and organizationally" (Hartmann and Linn, 2008).

The information included in the enablers and barriers section (Section 3.4) and in the current experiences section (Section 4) represents a succinct and valuable summary of conditions and factors that need to be taken into careful consideration during the upscaling process. Fig. 2 summarizes some of the main lessons emerging from the variety of experiences and sectoral expertise that was reviewed.

Although there is a large amount of knowledge reviewed here there are questions that remain unanswered and that relate explicitly to the

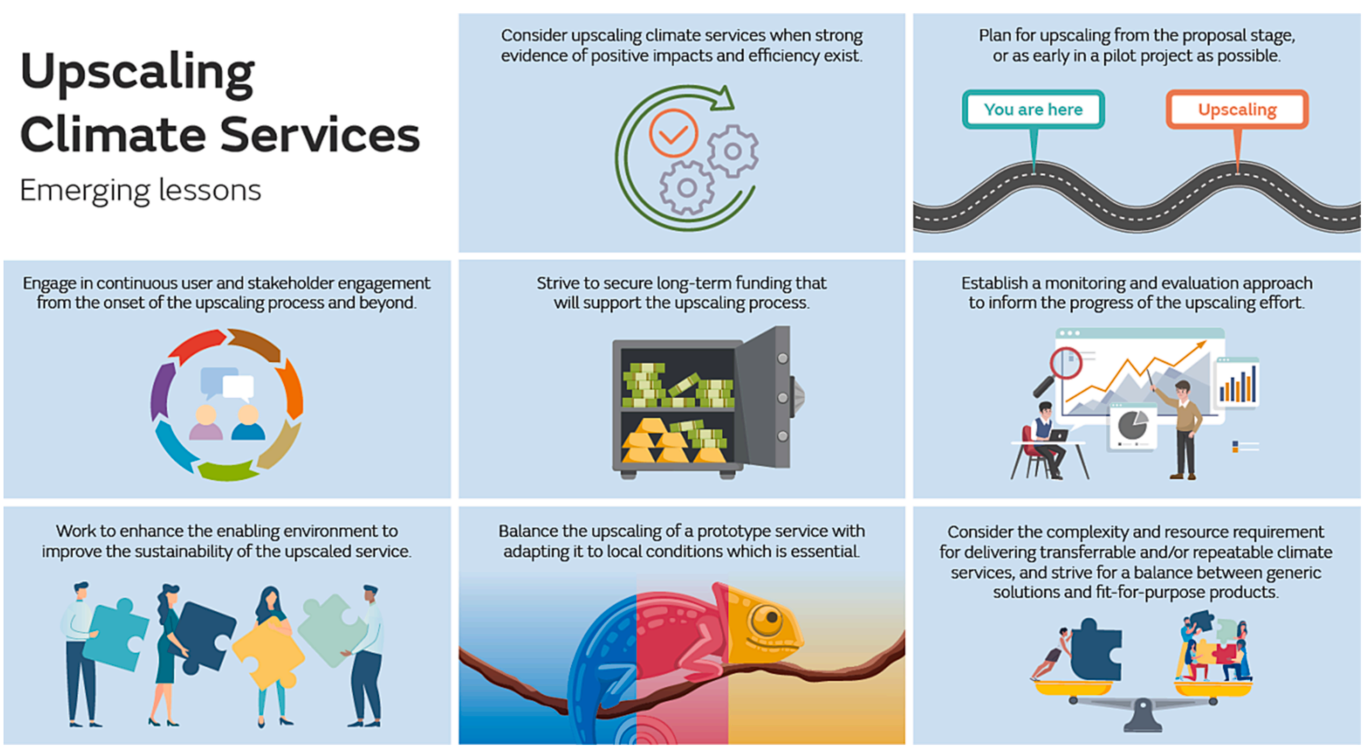

Fig. 2. Lessons learned about upscaling climate services, emerging from existing experiences and sectoral expertise.

nature of climate services: When, or for which services, should upscaling be considered? How to apply the upscaling concepts and the ideas from this review to climate services in an efficient, effective, and sustainable manner? How to increase efficiency during the transition to repeatable and/or transferrable services, as well as during user engagement and co-production? How to find the balance between developing services on a bespoke basis vs more reproducible and efficient (but still relevant) services – to what extent is there an optimum position in this continuum?

Our future work will build on this foundation by exploring existing frameworks and toolkits for scaling readiness assessments and for developing a strategic approach to upscaling (including those mentioned in Section 3.2). Their applicability in the context of provision of climate data and information will be evaluated, in order to create a toolkit that facilitates the climate services upscaling approach. Testing the elements of this toolkit via several case studies that have an upscaling dimension will allow us to learn, adapt and improve our approach, and thus refine the upscaling toolkit before publishing it on-line for use by others and further feedback. The approach, and its development via the case studies, is the subject of a future paper that is in preparation.

The purpose of undertaking this work was to provide the foundation for development of a set of flexible steps and criteria that can be implemented, from the outset, by climate service providers to support the assessment of a climate service's potential to be upscaled and to organize the upscaling process. Our focus has been predominantly on upscaling of services created within government and research institutions; however, we believe that this literature review also provides valuable information to private-sector companies involved in the provision of climate services, because our interactions with representatives of such organizations suggest that they face similar upscaling challenges to their counterparts in government and research institutions. Our intention is that this summary of knowledge and expertise from various sectors will be a useful introduction and an impetus to others engaged in developing of climate services to focus their efforts on upscaling armed with a greater knowledge and understanding of the conditions that can support successful implementation and distribution.

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.

Data availability

No data was used for the research described in the article.

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Appendix A. – Summary table of various terms used to indicate horizontal and vertical upscaling in the literature

Appendix B. – List of factors conducive to upscaling

- **Innovation characteristics** - Intervention (product) characteristics (Gillespie et al., 2015), keep innovations simple (World Health

Table A1
Summary table of various terms used to indicate horizontal and vertical upscaling in the literature.

Horizontal scaling		
Other terms used or different understanding of the term	**Mentioned in**	**Sector**
Scaling out	Aggarwal et al., 2018	CS for agriculture
	Smeds, 2020	Urban services
	Lambin et al., 2020	Sustainability
	Tran et al., 2020	Agriculture
Outscaling	Hermans et al., 2017; Seifu et al., 2020	Agricultural research for development
Spread (through replication)	Greenhalgh and Papoutsi, 2019	Healthcare
	Bradach, 2003	Social programs
Dissemination	Gündel et al., 2001	Natural resources management
Scaling up, replication	World Health Organization, 2009; World Health Organization, 2010	Health
Expansion	Hartmann and Linn, 2007; Holcombe, 2012; Jonasova and Cooke, 2012;	Development
	Wigboldus et al., 2016; Poudel et al., 2017; Tall et al., 2013	Agriculture
Transfer	Jonasova and Cooke, 2012	Development
Scaling down - within a group or livelihood of similar users and under similar conditions	Tran et al., 2020	Agriculture
Horizontal diffusion among organizations at the same administrative level	Hermans et al., 2017	Agricultural research for development
Quantitative scaling up	Gündel et al., 2001: their Table 1	Natural resources management
Horizontal upscaling which occurs voluntarily between leading cities	Kern, 2019	Cities and climate governance
Vertical scaling		
Other terms used or different understanding of the term	**Mentioned in**	**Sector**
Scaling up	Aggarwal et al., 2018	CS for agriculture
	Smeds, 2020	Urban services
	Seifu et al., 2020	Agricultural research for development
	World Health Organization, 2009	Health
	Tran et al., 2020	Agriculture
	Woltering et al., 2019	
	Poudel et al., 2017	
Upscaling	Hermans et al., 2017	Agricultural research for development
	Sulaiman et al., 2018	Agriculture
Political scaling, functional scaling	Gündel et al., 2001: their Table 1	Natural resources management
Organizational scaling up - related to institutional development meaning "to improve efficiency and effectiveness to allow for growth and sustainability of interventions".	Gündel et al., 2001: their Table 1	Natural resources management

(*continued on next page*)

Table A1 (*continued*)

Horizontal scaling		
Other terms used or different understanding of the term	**Mentioned in**	**Sector**
Vertical upscaling - happens between leader and follower cities and higher level of government	Kern, 2019	Cities and climate governance
Hierarchical upscaling which focuses on harmonization of policies at the national or EU level and sets mandatory standards for all municipalities	Kern, 2019	Cities and climate governance
"The adoption of donor-funded innovations beyond their original project settings and time periods."	Woltering et al., 2019	Development
Increase in size, speed	Wigboldus et al., 2016	Agriculture
Scaling within sectors	Lambin et al., 2020	Sustainability
Institutional uptake or embedding of processes or technologies by organizations at higher administrative levels	Hermans et al., 2017	Agricultural research for development

Organization, 2011), credible, observable, relevant, relative advantage, easy to install and understand, compatible, testable (CORRECT) (World Health Organization, 2009), simplify innovation for ease of use (World Health Organization, 2010), strong scientific basis (Cavelier et al., 2017), successful combination of 'hardware', 'software' and 'orgware' (Hermans et al., 2017), have clear and testable design, local legitimacy, ownership and capacity to produce benefits, keep innovations simple (Holcombe, 2012), improve resolution of information, use climate impact models, affordable information, common data formats and standards (Perrels et al., 2019), diversity and content of product, format, dissemination, timing, spatial coverage can be enablers (Tran et al., 2020).

- **Relevance** - Attention to specific spatial and temporal context, objectives, users and beneficiaries (Sartas et al., 2020), local scale (Tall et al., 2014), use local knowledge (Tall et al., 2014), contextually relevant strategies and pathways for scaling (Gillespie et al., 2015), ensure relevance of innovation (World Health Organization, 2011), tailor innovation to sociocultural and institutional settings (World Health Organization, 2011), relevant technical options, farmer centered approach (Gündel et al., 2001), adapting innovations to various contexts (World Health Organization, 2009), adaptation of tested innovations to local settings (Simmons et al., 2007), align climate services (CS) with decision-maker needs (Hansen et al., 2019), CS more relevant to users (Cavelier et al., 2017), test and adapt new practices to new context (Sulaiman et al., 2018), use context based approach to scaling (Totin et al., 2020), context specificity (Westermann et al., 2015), tailored services (Kaur et al., 2015), user relevant aspects of service delivery (visualization, risk indicators, collaborative CS development) (Perrels et al., 2019), need-based approach, tailor CS to demand (Tran et al., 2020).

- **Tested evidence** - Proof of implementation feasibility (World Health Organization, 2011), caution not to scale-up before needed evidence is available (World Health Organization, 2011), testing provides information on implementation in real world (World Health Organization, 2009), economic evidence recognized (Cavelier et al., 2017), show success stories and added value (Perrels et al., 2019), successful examples at local scale (Tran et al., 2020), solid evidence for scaling, tangible results and benefits for users (Koerner et al., 2020).

- **Monitoring and evaluation** - (Sartas et al., 2020), mechanisms for monitoring, learning and accountability (Gillespie et al., 2015), test in the variety of sociocultural and institutional settings where it will be scaled (World Health Organization, 2011), test under routine operating conditions and resource constraints of the system (World Health Organization, 2011), develop plans to assess and document the process of implementation (World Health Organization, 2011), indicators and measures of success, accountability (Gündel et al., 2001), critical for sustainability and to be planned from beginning (Tall et al., 2013), systematic use of evidence (Simmons et al., 2007), upscaling needs monitoring and evaluation (Hartmann and Linn, 2007), monitoring and evaluation – continuous, independent, dynamic (Holcombe, 2012), monitoring and evaluation (Jonasova and Cooke, 2012), monitoring and ex-post evaluation of CS (Perrels et al., 2019), key performance indicators to be tracked (Bradach, 2003), cost-benefit assessment (Tran et al., 2020).

- **Vision, planning, strategy** - Clear vision or goal of impact (Gillespie et al., 2015), consensus on expectations for scale-up (World Health Organization, 2011), effective management, consider sustainability, market development (Gündel et al., 2001), design and test innovations with scaling up in mind (World Health Organization, 2009), design innovations with upscaling in mind, ongoing focus on sustainability (Simmons et al., 2007), plan to address human resource shortages (World Health Organization, 2010), needs systematic planning (World Health Organization, 2010), consider values of upscaling (Hartmann and Linn, 2007), upscaling needs orderly and gradual process, needs to be systemic effort (Hartmann and Linn, 2007), clearly defined 'Theory of change', plan for upscaling in the design of the pilot (Holcombe, 2012), flexibility of scaling process (Totin et al., 2020), formulate and address critical assumptions (Westermann et al., 2015), clarity about implementing organization (Jonasova and Cooke, 2012), show success stories and added value, align with sectoral, cross-sectoral and non-sectoral demand (Perrels et al., 2019), strong theory of change, greater number of important elements to be standardized (Bradach, 2003), credibility (Koerner et al., 2020), effective exit strategy, clear delineation of roles (Singh et al., 2016).

- **Leadership** – effective leadership in user org (World Health Organization, 2009), effective and motivated leaders in resource team (suppliers) (World Health Organization, 2009).

- **Engagement with users** - Engagement with local stakeholders from onset (Woltering et al., 2019), voice to farmers in design, production and evaluation, participatory action-research approaches (Tall et al., 2014), face-to-face dialog (Tall et al., 2014), interaction opportunities (Blundo-Canto et al., 2021), engage in participatory process with key stakeholders – build ownership (World Health Organization, 2011), use of participatory approaches, sense of ownership (Gündel et al., 2001), involve farmers in policy development and planning (Tall et al., 2013), stakeholder trust and commitment (Totin et al., 2020), bi-directional communication with users – how they define quality (Perrels et al., 2019), involve users in design, production and evaluation of products (Tran et al., 2020), dialog and narrative, early engagement with users – crucial, tools more effective when users develop them (Koerner et al., 2020), co-production of meaningful and actionable climate information, give users a voice – participatory process (Singh et al., 2016).

- **Equity** - consider gender and human rights (World Health Organization, 2009), ensure women, poor and socially marginalized groups are served (Tall et al., 2013), equity is important (Bradach, 2003), attention to vulnerable groups (Tran et al., 2020), ensure women engagement (marginalized groups) (Singh et al., 2016).

- **Partnerships** - Multi stakeholder agreement (Sartas et al., 2020), collaboration between actors (Woltering et al., 2019), sustained interactions between climate forecasters, agro organizations, farmers (Tall et al., 2014), strong professional buy-in (Greenhalgh and Papoutsi, 2019), partnerships (catalyst role, networking, user-driven, multiple stakeholders) (Gündel et al., 2001), coalition of various partners with aligned motivations, use complementary capabilities of various actors (Lambin et al., 2020), active sponsorship and concerted effort from multiple stakeholders (Simmons et al., 2007), work with religious or political leaders to gain acceptance of innovation (World Health Organization, 2010), coordinated delivery of information by public research institutes concerned with climate change (CC) (Cavelier et al., 2017), increase collaboration, broad and dense multidisciplinary networks (Hermans et al., 2017), interactions, organization and agreement between multiple actors (Sulaiman et al., 2018), multi-stakeholder platforms and policy making networks, strong partner engagement, interactions with diff types of partners (Westermann et al., 2015), engaging stakeholders from different sectors, coordination between organizations (Kaur et al., 2015), enable collaboration between different actors to support learning (Perrels et al., 2019), leverage networks and find partners (Bradach, 2003), coordination, leverage partnerships, link all levels (Koerner et al., 2020), create new and non-traditional relationships, involve private sector, ownership by multiple actors (Singh et al., 2016).

- **Intermediaries/champions** - Importance of intermediary actors (opinion leaders, change agents, gatekeepers) for successful adoption and implementation (Nilsen, 2015), establish drivers – champions, catalysts, incentives, systemwide ownership (Gillespie et al., 2015), create champions (World Health Organization, 2011), institutional entrepreneurs who can keep the system moving (Lambin et al., 2020), develop a new cohort of adaptation professionals (Cavelier et al., 2017), influential persons or organizations (Hermans et al., 2017), champions at every level, need intermediaries (could be government) (Holcombe, 2012), champions (Jonasova and Cooke, 2012), use champions (Perrels et al., 2019), find local champions (Bradach, 2003), champions (Koerner et al., 2020), strong champions and intermediaries (Singh et al., 2016).

- **Communication and learning** - Communication technologies (Tall et al., 2014), knowledge sharing and action platforms, capacity strengthening (Blundo-Canto et al., 2021), promote learning and disseminate information (World Health Organization, 2011), consider local capabilities, capacity building, consensus building (Gündel et al., 2001), consider users' institutional capacity (World Health Organization, 2009), multidisciplinary learning networks and comms platforms, respect users' experience and cultural values (Tall et al., 2013), build local capacity for innovation (Simmons et al., 2007), build training capacity in user organization (World Health Organization, 2010), invest in capacity of decision makers to use the innovation (Hansen et al., 2019), develop and promote good practice standards (Hansen et al., 2019), support education and training (Cavelier et al., 2017), increase of knowledge sharing (Hermans et al., 2017), capacity development of all stakeholders (Sulaiman et al., 2018), capacity enhancement (Westermann et al., 2015), engage in double-loop learning (Westermann et al., 2015), understand the pathways and stakeholders involved in effective adaptation, communicate CC and risks effectively to diff audiences, learning from places where adaptation is successful (Williams et al., 2012), communicate in simple and understandable ways (Kaur et al., 2015), raise awareness of sectoral or regional climate-related risks and opportunities (Perrels et al., 2019), consider people skills locally (Bradach, 2003), educate users on climate risks and impacts, access to info specific for context and situation, interactive methods across the CS value chain (Tran et al., 2020), participatory bi-directional learning process, strengthen capacities, learn as we go (Koerner et al., 2020), improve climate info production and communications (Singh et al., 2016).

- **Financing** - Investment (Smeds, 2020), sourcing local financing (Woltering et al., 2019), investment in capacity (Tall et al., 2014), financial support (Blundo-Canto et al., 2021), generous resourcing (Greenhalgh and Papoutsi, 2019), adequacy, stability and flexibility of financing (Gillespie et al., 2015), advocate for financial support beyond the pilot stage (World Health Organization, 2011), financial sustainability (Gündel et al., 2001), maintain balance of incentives, design institutions with reasonable transaction cost (Lambin et al., 2020), availability of financial resources (World Health Organization, 2009), mobilize and coordinate CS investments (Hansen et al., 2019), upscaling needs incentives (Hartmann and Linn, 2007), investments in knowledge, technologies and human capital (Poudel et al., 2017), prioritize resources for adaptation (Williams et al., 2012), incentives, coordinated investments in enabling factors, financial stability, resources (Jonasova and Cooke, 2012), public budgeting, economic growth, realistic and viable business models, create incentives (Perrels et al., 2019), reliable source of funding (Bradach, 2003), develop new business models for funding (Tran et al., 2020), earmark budgetary support for sustained multi-stakeholder interactions (Singh et al., 2016).

- **Institutional and enabling environment** - Attention to the organizational and institutional processes related to the product/practice (Woltering et al., 2019), institutional support (Aggarwal et al., 2018), institutionalizing change into routine systems (Woltering et al., 2019), consider economic, spatial, technical, political systems (Woltering et al., 2019), projects should be a building block in a wider program – sector- or country-development strategies (Woltering et al., 2019), institutional arrangements (Tall et al., 2014), political support (Blundo-Canto et al., 2021), positive policy context (Greenhalgh and Papoutsi, 2019), enable organizational context (Gillespie et al., 2015), operational and strategic capacities (Gillespie et al., 2015), adequate governance structures and systems (Gillespie et al., 2015), create political commitment (World Health Organization, 2011), prepare to advocate for necessary changes in policies, regulations, and other system components (institutionalization usually happens after demonstrated success of project) (World Health Organization, 2011), change policies to create enabling environment (Gündel et al., 2001), scaling often involves institution building task (World Health Organization, 2009), link to sectoral reforms (World Health Organization, 2010), promote formal institutional and policy arrangements (Hansen et al., 2019), shift national met data policy from source of revenue to public good (Hansen et al., 2019), upscaling needs political constituencies (Hartmann and Linn, 2007), including adaptation in regulation and tenders, certification of CS to keep high level of quality (Cavelier et al., 2017), clearly defined competencies among diff agencies (Holcombe, 2012), policies to be coherent across institutions (Poudel et al., 2017), favorable enabling environments, policies, investments (Sulaiman et al., 2018), greater engagement of state institutions and stakeholders (Tanner et al., 2019), consider existing conducive context, link to government policies and interventions (Totin et al., 2020), strong grounding in existing or national multi-stakeholder platforms (Westermann et al., 2015), Normalising of simultaneous mitigation and adaptation practices, and their introduction into organisations' long-term planning and day-today activities, integrating adaptation into existing public and policy agendas, clearer responsibilities for adaptation, adaptation embedded in planning policies (Williams et al., 2012), influencing organizations that support scaling, government commitment and leadership, external catalysts (e.g., government strategy) (Jonasova and Cooke, 2012), more coherent policy for promotion of CS use, obligations to systematically report CC risks, standardization of products, ratings, QA of CS, strengthening and harmonizing climate resilience legal framework (Perrels et al., 2019), holding constant the context in which a program will operate – financial structure for example (Bradach, 2003), link to national and regional frameworks for CS, engage with policy-makers to develop framework to integrate CS processes (Tran et al., 2020), advocacy (Koerner et al., 2020), integrate CS into gov policy and planning, supportive institutional framework (Singh et al., 2016).

- **Various** - Long time scale (Greenhalgh and Papoutsi, 2019), longer time scales (World Health Organization, 2009), need for research on upscaling (Simmons et al., 2007), improve usability of nationally produced climate information, fill observational data gaps (Hansen et al., 2019), external catalysts of upscaling are crises, natural disasters, economic meltdown (Hartmann and Linn, 2007), behavior change (Holcombe, 2012).

Appendix C. – List of factors that can obstruct upscaling

- **Innovation characteristics** - targeting and design of product

(Hellin et al., 2017), legitimacy (Tall et al., 2014), too focused on technological solutions (Gündel et al., 2001), legitimacy (Tall et al., 2013), credibility and uncertainty of climate information (Hansen et al., 2019), systemic innovation failure (Hermans et al., 2017), information is too long and incomprehensive, seasonal forecasts based on zones and not downscaled, quality of information (Kaur et al., 2015), reliability of data and the confidence in CS, uncertainty of data for CS (Tran et al., 2020).

- **Relevance** - salience (Tall et al., 2014), fine grain information (Blundo-Canto et al., 2021), what works in one area does not necessarily work in another (Wigboldus et al., 2016), salience – tailoring content, scale, format and lead-time to farm-level decision making (Tall et al., 2013), different timeframes for climate impacts and planning investments, difficult to translate CC impacts in economic terms (Cavelier et al., 2017).

- **Monitoring and evaluation, testing** - impact evaluation (Hellin et al., 2017), lack of evaluation and rewards to encourage application (Seifu et al., 2020), inadequate evidence base for Climate Smart Agriculture (CSA) tools and practices (Poudel et al., 2017), lack of evidence on the (cost)-effectiveness of forecast-based early Action approaches (Tanner et al., 2019), lack of effective, timely M&E (Jonasova and Cooke, 2012), challenge to find solid evidence on scaling due to missing impacts assessments (Koerner et al., 2020).

- **Vision, strategy and planning** - low innovation readiness (Sartas et al., 2020), integration (Tall et al., 2014), lack of involvement of private sector, inability to keep pace with increase in uses and users (Blundo-Canto et al., 2021), large-scale implementation not considered at the time of pilot or field-testing (World Health Organization, 2011), pilot case is not generally applicable (Gündel et al., 2001), integration - limited understanding of usability in action by farmers (Tall et al., 2013), integration – difficult to integrate available climate information in existing practices and workflows (Cavelier et al., 2017), no adequate attention on sustainability of practices (Poudel et al., 2017), problems of strategy and management (Bradach, 2003).

- **Understand the system or process** - capturing the full value chain (Hellin et al., 2017), failure to understand the system well, poor conceptual and methodological clarity on what scaling is and how to do it – narrow focus on reaching numbers (Woltering et al., 2019), scaling is not linear (Wigboldus et al., 2016), local projects have 'programme placement' and 'self-selection' biases (Gündel et al., 2001).

- **Leadership** - lack of charismatic leadership (Gündel et al., 2001), lack of management capacity (Hartmann and Linn, 2007).

- **User engagement** – engagement and co-production (Hansen et al., 2019), making commitments to stakeholders without understanding their needs (Koerner et al., 2020).

- **Equity** - equity (Tall et al., 2014), limited access to social data by gender and difficult and costly to obtain (Tall et al., 2013), risk that small-scale farmers, the poor, women, and ethnic minorities, are left out (Tran et al., 2020).

- **Partnerships/intermediaries** - influential org (high-level gov actors) are often not part of multi-stakeholder platforms or are not actively linked, sparse, disconnected innovation networks (Hermans et al., 2017), lack of champions (Perrels et al., 2019), (lack of) cooperation with diff stakeholder groups (Koerner et al., 2020), (inability to) sustain effective long-term partnerships among multiple stakeholders (Singh et al., 2016).

- **Access and communication** - distribution channels and use of technology (Hellin et al., 2017), access (Tall et al., 2014), timely access to remote communities with marginal infrastructure (Tall et al., 2013), info sent via email but people may not have access to internet, not native language but English in bulletins – literacy of farmers, limited reach, info not timely (Kaur et al., 2015), more effective communication essential for continued public support and increases chances for sustainability, engagement of poor and remote communities – weak infrastructure, local language, literacy constraints (Jonasova and Cooke, 2012), access to information - poor infrastructure and channels for communication as well as, language barriers, cost to translate (Tran et al., 2020).

- **Learning** - lack of knowledge and limited facilitation skills (Seifu et al., 2020), fragmentation of knowledge (Hansen et al., 2019), difficult to understand current climate info and uncertainty (Cavelier et al., 2017).

- **Capacity** - lack of capacity (Smeds, 2020), building capacity and trust at a large scale (Blundo-Canto et al., 2021), capacity constraints within Nat Met Services, limited capacity and experience in working directly with farmers; low level of capacity of farmers to apply the info (Tall et al., 2013), weak capacities to implement innovation (World Health Organization, 2010), lack of capacity (Hansen et al., 2019), inadequate capacities across the relevant institutions in terms of human and financial resources (Poudel et al., 2017), training staff in climate information services who can interpret (Kaur et al., 2015), lack of interactive support for users (Perrels et al., 2019), capacity building for intermediaries (Singh et al., 2016).

- **Funding** - existing capital/funding (Aggarwal et al., 2018), lack of funding (Lugen, 2020), lack of resources (esp. financial, Seifu et al., 2020), local projects are subsidized – how to continue this (Gündel et al., 2001), support with resources (Gündel et al., 2001), few resources (World Health Organization, 2010), transaction costs (Sulaiman et al., 2018), lack of commitment to fund (Tanner et al., 2019), transaction costs (to reach large numbers, to meet farmers' priorities) (Westermann et al., 2015), lack of funds, technology and equipment (Kaur et al., 2015), lack of viable resourcing models for products which will often need updates (Perrels et al., 2019), lack of money – donor fatigue (Bradach, 2003), the human resources and additional funding required for scaling CS (Tran et al., 2020), problems with business models perspective and finding cost effective scaling models, lack of stable funding (Koerner et al., 2020), funding beyond the pilot phase (Singh et al., 2016).

- **Enabling environment** - sector not main priority at local level (Aggarwal et al., 2018), regulatory environment, enabling environment (Hellin et al., 2017), political learning between stakeholders, scaling up policies (vertical) to complement scaling out (horizontal) (Smeds, 2020), pilot set up in very controlled environment (Woltering et al., 2019), NGOs are bureaucratic – need to decentralize management (Gündel et al., 2001), macro and institutional environments are unfavorable (Gündel et al., 2001), formalize collaborative arrangements (Gündel et al., 2001), systems have weak capability to implement innovation and may be characterized by multiple pressing priorities (World Health Organization, 2010), lack of cohesiveness of the CS community, growing number of organizations providing CS (Hansen et al., 2019), donors shift priorities, governments change, NGO funding is driven by fashion, agency managers and staff move in and out, no support for the scaling process - inertia (Hartmann and Linn, 2007), linkages between local and higher levels are weak (Hermans et al., 2017), diffused decision power, complexity and demands for coordination (Holcombe, 2012), weak coordination among actors (within government agencies and between government and the private sector), limited coherence in priorities, existing institutional capacity and coordination mechanisms among the government departments, private sector actors and non-governmental organisations (Poudel et al., 2017), issues with institutional enabling environment (Sulaiman et al., 2018), Institutional incentives and finance are still skewed towards relief, post-disaster response is seen as more visible and defensible, forming a barrier to early actions, change can often be co-opted by politically and economically powerful groups to suit their own interests, competition between agencies (Tanner et al., 2019), lack of institutional embedding, mistrust or lack of commitment among parties (Perrels et al., 2019), lack of CS policies for users and their needs (Perrels et al., 2019), prevailing bias among funders to support innovative "breakthrough" ideas, replication is considered linked to bureaucracy and centralized control (Bradach, 2003), collaboration between different institutions, changes in gov structures or staff (Tran et al., 2020).

- Other - data availability (Hellin et al., 2017), gaps in information/data (Hansen et al., 2019), long-term horizon of scaling (Hartmann and Linn, 2007), users' attitudes and objectives (Sulaiman et al., 2018), risk of 'acting in vain' (Tanner et al., 2019), CS is often not considered worth the cost, taxonomy only focused on providers and users – need market taxonomy on value networks (Perrels et al., 2019), confidence in diff elements of CS value chain (Tran et al., 2020), high staff turnover, donors push for 'numbers' pushes the limits of research (Koerner et al., 2020).

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