ASSESSMENT OF THE EXISTING RESOURCING AND QUALITY ASSURANCE OF CURRENT CLIMATE SERVICES

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List of Abbreviations

Abbreviation	Full name and explanation
C3S	Copernicus Climate Change Service, part of COPERNICUS
CLIPC	Constructing Europe's Climate Information Portal; former FP7 project
COPERNICUS	Sub-programme in H2020 research programme oriented to earth observation and derived services, including C3S
CORDIS	Community Research and Development Information Service (European Commission)
CS	Climate services
CSA	Coordination and Support Action
CSP	Climate Services Partnership
CTA	Constructive Technology Assessment (see glossary)
ECCA	European Climate Change Adaption Conference
ECLISE	Enabling CLimate Information Services for Europe; former FP7 project
ECMWF	European Centre for Medium-Ranged Weather Forecast
ECV	Essential Climate Variables
ENHANCE	Enhancing Risk Management Partnerships for Catastrophic Natural Hazards in Europe; former FP7 project
ESGF	Earth System Grid Federation – International inter-agency initiative for open source robust, distributed data and computation platform, enabling worldwide access to Peta/Exa-scale scientific data
EU-LIFE	LIFE is the EU's financial instrument supporting environmental, nature conservation and climate action projects throughout the EU.
EUMETSAT	European Organisation for the Exploitation of Meteorological Satellites; is an intergovernmental organisation with the purpose to supply weather and climate-related satellite data, images and products
EUPORIAS	European Provision of Regional Impacts Assessments on Seasonal to Decadal Timescales; former FP7 project
FP6	Sixth Framework Programme; EU Research Funding 2002 – 2006
FP7	Seventh Framework Programme; EU Research Funding 2007 – 2013
GCOS	Global Climate Observing System; is intended to be a long-term, user-driven operational system capable of providing comprehensive observations required for

	monitoring the climate system, detecting and attributing climate change, assessing impacts of, and supporting adaptation to, climate variability and change
GEOSS	Global Earth Observation System of Systems; a set of coordinated, independent Earth observation, information and processing systems that interact and provide access to diverse information for a broad range of users in both public and private sectors
GFCS	Global Framework for Climate Services (WMO initiative)
H2020	Horizon 2020, current research and innovation programme of the European Union
HPC	High-performance computing
IMPACT2C	Quantifying projected impacts under a 2°C warming; former FP7 project
Interreg	European Territorial Cooperation; Interreg is part of the EU's structural and investment policy and supports cross-border infrastructure, job market integration and cultural exchange
ISO	International Organisation for Standardisation; international standard-setting body composed of representatives from various national standards organizations; ISO numbers refer to particular protocols.
MARCO	Market Research for a Climate Services Observatory; currently running project under H2020; based on the same call (SC5-03a/b); close cooperation with EU-MACS
NDA	Non-disclosure agreement
NMS, NHMS	National Meteorological Service, National Hydro-meteorological Service (standard abbreviations in WMO context)
NWS	National Weather Services
QA	Quality Assurance (see glossary)
R&D	Research and Development
SECTEUR	Sector Engagement for C3S: Translating European User Requirements; currently running C3S project
SPECS	Seasonal-to-decadal climate Predictions for the improvement of
UNEP	United Nations Environment Programme
UNESCO	United Nations Educational Scientific and Cultural Organization
UNFCCC	United Nations Framework Convention for Climate Change
WCRP	World Climate Research Programme
WMO	World Meteorological Organization
WP	Work package

Glossary of terms

Term	Explanation
climate service	The transformation of climate related data – often together with other relevant information - in to customized information products, offered as such or embedded in consultancy and/or education [condensed version of European Roadmap definition]

climate service: seasonal forecast	A prediction of weather tendencies (often expressed as probabilistic deviations from long term averages typical for the considered period and area) stretching from approx. 1 month to 6 months or more. Less than two months is usually defined as sub-seasonal.
climate service: long term forecast	A prediction of climate conditions for a certain area and for typical time units (diurnal to annual) referring to decadal or multi-decadal averages several to many decades ahead
climate service provider	An organisation that offers climate service products based on own and/or acquired data from observations and simulations with the aim to serve others in the climate services value chain as pure public good, as controlled open data, or as priced product; apart from national meteorological institutes (NMS) providers are mostly also users of CS, i.e. needing to acquire climate data from others.
climate service purveyor	An organisation that largely focuses on mediating of climate services, the value added of these services is largely in improving access and presentation of CS
climate service user	An organisation which user CS for the purpose of improving its own products and services, as well as for better management of risks.
Constructive technology assessment (CTA)	The modulation of ongoing technological developments by 'soft intervention' aiming at a better understanding of the technology in focus and its impacts. There are three generic strategies for CTA: technology forcing, strategic niche management, and loci for alignment.
remote sensing	A set of technologies meant to observe – in visible light or at other wavelengths – the state and development of the atmosphere, oceans, land, land use and the biosphere from above by flying over it following dedicated routes (drones; airplanes) or prefixed orbits (satellites)
market	A medium, physically located or virtual, where supply and demand of near substitutes of products and services meet with the purpose to engage in mutually beneficial transactions between suppliers and demanders; a perfect market is fully transparent for all actors in terms of prices and product features, whereas no actor has a dominating position, and new suppliers and users can easily enter
market failure	The situation where a market has imperfections as compared to the theoretically defined state of 'perfect competition' , such as shortcomings in price and/or product transparency, presence of market dominance, and barriers to entry
business model	The representation of a firm's underlying core logic and strategic choices for creating and capturing value; in a more practical sense it are the conditions and assumptions by means of which a provider or purveyor offers products and realizes transactions
sector	In economics: a coherent cluster of economic activities categorized by means of standardized (international) classification such as SIC (e.g. sector: agriculture, sub-sector: dairy farming) - in some cases ad-hoc reclassifications are applied; in other social sciences 'sector' may have a somewhat more flexible meaning, i.e. all actors (producers, users, facilitators, regulators, etc.) involved in a certain (thematic) area of interest.
Seamless prediction	Instead of separate scale-based predictions (minutes, days, weeks, months, years, decades …), an integrated prediction process that combines all temporal and spatial scales.
value chain	The pathway of processing stages of a product or service through which value is added; a complex product with abundant economies of scope such as a climate service (for a particular purpose) can often evolve through more than one pathway, while more pathways may be added (and others abandoned) over time; how and how strongly value accumulates and to whom it accrues when progressing in the value chain depends not only on the pathway, but also on the degree of regulation of the market, the market position of various actors, and the pace of innovation.

quality	The extent to which a product or service meets the specifications of the customers, and by extension the specifications within the production process needed to attain the quality levels of final products as required by customers.
quality assurance	The processes and protocols by means of which an organization *assesses* the apparent quality of its products and its constituent elements, and communicates the aspired and observed quality levels within the organization as well to providers and customers.

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NON-TECHNICAL SUMMARY

The project EU-MACS is funded by the EU (Horizon programme) and aims to clarify how the market for climate services could abound by improving the matching of supply of and demand for climate services (CS). CS are understood as services that include transformation of climate related data – often together with other relevant information - into customized information products, offered as such or embedded in consultancy and/or education. EU-MACS runs from November 2016 to November 2018. The study generates a series of Deliverables (mostly reports). This Deliverable 1.2 discusses (1) encountered business models and resourcing for CS provision, (2) quality assurance of CS provision, and (3) the significance of legislation in creating demand for CS.

Key points concerning business models and resourcing

- The greater part of *current* climate services (CS) related activities is realized under non-market conditions
- Resource use for CS research, development and piloting seems as yet much larger than for actual CS delivery
- Public funding of CS activities has been hitherto clearly more significant than private funding, but this can change significantly as more CS become operational and more user segments get activated
- CS are a class of sustainable innovations – building blocks for a sustainable transition of society, …
- … therefore many users cast CS as a flexible cluster of monitoring, information, analysis, decision support, advice, training and brokerage activities which serve adaptation, mitigation and/or coping with climate variability or even other environmental and socio-ecological issues
- (public-private) *partnerships* seem often a very suitable organisation type for CS delivery or for CS brokerage, enabling a broad and malleable collection of skills and data
- Various, mainly private sector, user segments adhere great value to timely and agile provision of climate services, and therefore prefer private climate service providers over others, also implying that partnerships may be used for brokerage but much less for actual CS delivery
- Consequent implementation of open data policy is important for the CS market to abound. Both for reasons of equitable balances between private and social benefits and for reasons of healthy data infrastructure continuity royalty systems could be considered, provided the principles and purposes of open data are not compromised
- In particular public CS providers and public-private partnerships for CS provision should pay sufficient attention to business model development and recurrent review, and in accordance with their position in the value chain; furthermore, also at the CS user side there may be options for sector or regional coordination or centralization of CS acquisition

Key points regarding quality assurance

- Quality assurance (QA) is not only a matter of control, but just as much of *communication*
- The more a CS involves tailoring, non-climate data, advice and training, or the more the user lacks expertise in climate and/or risk analysis the more QA should go beyond the statistical properties and origins of the climate data, and consider also linking feasibility with non-climate data as well as the service delivery process

- Broad scoped QA (beyond climate data properties) greatly benefits from or even requires interactive approaches such as co-design of the CS with the user – the so-called open model
- Quality uncertainty of CS concerns both the *performance uncertainty* (party covered with traditional QA) and the *product fit uncertainty* (addressed by broad scoped QA)
- Many CS providers are aware of the need for broader scoped QA, but point at the lack of available – applicability proven – indicators
- Broad scoped QA, including versatile feedback systems, can also support innovation in CS
- Broad scoped QA can include, where appropriate, the review of linking feasibility with non-climate data; for example the very thorough QA development efforts in the COPERNICUS C3S programme merit – at least exploratory – extensions with respect to selected non-climate data
- Social learning both among CS users and CS providers should be promoted in a systematic way as a means to improve matching of CS offers and needs, and thereby support the market growth of CS
- The enablement of social learning is one of the reasons to review possible time limitations of confidentiality conditions of publicly funded CS developments

Key points regarding legislation

- Many EU Member States have legislation in place, especially in relation to land use, urban planning, water, and physical infrastructure, that obliges or at least strongly recommends to account for effects of climate change
- Yet, the legislation or guidelines leave often a lot of leeway to the sector or regional decision makers how rigorous and with what kind of information the climate change impact and adaptation assessment is carried out, and consequently there is no strict obligation to use climate services or assure a certain quality level of these services – hence standards are set by how the practice develops
- In the finance sector emerges interest in defining national and international reporting obligations with respect to exposure to climate risks, which encompasses both asset value risks of climate (mitigation) policy and various value loss risks related to climate change impacts

PART A –

Common Introduction

1. INTRODUCTION

1.1 The study

To support further product development and effective widespread uptake of climate services, as a means to boost mitigation of and adaptation to climate change as well as capabilities to cope with climate variability, the European Commission has included several actions in its current research programme Horizon 2020 (H2020). Essentially these actions follow from the logic to implement the European Research and Innovation Roadmap for Climate Services (cf. European Commission, 2015)

EU-MACS and it sister project MARCO deal with analysis of the climate services market. In addition demonstration calls were launched on the added value of climate services for supposedly high value added sectors with hitherto little uptake of climate services (SC5-01-2016-2017), while other actions focus more on networking activities interlinking to better connect relevant players (e.g. the ERA-NET for Climate Services (SC5-02-2015) and the project funded under the Coordination and Support Action (SC5-05b-2015) called Climateurope.

An extremely important sub-programme in H2020 is the COPERNICUS Climate Change Service (C3S) programme, which aims to generate a very comprehensive coherent and quality assured climate data set meant to support mitigation and adaptation planning, implementation and monitoring. In due course also coping capabilities of (current) climate variability are addressed.

In this framing, EU-MACS – European Market for Climate Services – will analyse market structures and drivers, obstacles and opportunities from scientific, technical, legal, ethical, governance and socioeconomic vantage points. The analysis is grounded in economic and social science embedded innovation theories on how service markets with public and private features can develop, and how innovations may succeed.

1.2 Scope and remit of this report

This Deliverable 1.2 covers the output of Tasks 1.2 and 1.3, dealing with business model and resourcing, and with quality assurance respectively.

Task 1.2 is designed to collect knowledge about and assess the financial value of the markets of climate services (hereafter CS), make an inventory of business models, types of cost recovery, and financial and human resourcing for both CS suppliers and users. This Task will also study factors that determine or influence the willingness-to-pay (WTP) for the marketed services, so as to provide guidance to the WTP assessments in WP2-WP4. In parallel, we review and analyse the future resourcing outlooks and foresights with the sectors analysed in this project. We will base our analysis on literature review, interviews, targeted surveys and in-depth assessment of selected climate services.

Task 1.3 assesses the role and significance of quality assurance in CS in terms of juridical basis, ethical aspects (good conduct in service provision and use), technical and administrative feasibility (standards, branding) and economic effects (very strict quality requirements may hamper market development due to extra costs and complexity). Both current practices and plausible extensions are reviewed. The work will be based on a literature review, a quick scan of CS websites, a comparison with similar information services for other policy areas (notably energy efficiency promotion), interviews with CS providers, and participation in the Task 1.1 survey with questions pertaining to the management, perception and communication of quality of climate services as well as to the resourcing of climate services.

During the realization of Tasks 1.2 and 1.3 it became apparent that a very substantial share of the supply climate services is not offered and matched with demand in what economists would regard a 'market for climate services' (see also glossary), instead a substantial part of the activities has an R&D or otherwise a quite exploratory character. For these reasons it was regarded that there is not much point in paying particular attention to the validity of findings for a WTP analysis at this stage, even though indeed some of the findings are relevant input for a WTP analysis. We will reconsider the application of WTP in later stages of one or more of the work packages 2 – 4, or conduct it in the context of WP5.

The output of these Tasks is meant to function as:

- Input for the work packages 2 – 5, in terms of identifying obstacles, solutions, and consequences that merit further attention;
- Contribution to the overall mapping of the climate services market or sector in terms of its current functioning, and explanation of key mechanisms.

Resourcing and quality assurance were seen as important elements in the evolving climate services market, which hitherto had received moderate attention in the largely descriptive studies. These elements are also interacting, as thorough quality management and assurance of the whole value chain requires substantial resources, and vice versa budget limitations will require priority setting in quality assurance (for CS providers) and quality demands (for CS users). This interaction motivated to report the Tasks in one Deliverable.

Task 1.2 was coordinated by CMCC with contributions of Acclimatise, FMI and UnternehmerTUM, while Task 1.3 was coordinated by FMI with contributions from GERICS, and feedback from Joanneum, and Acclimatise.

The reader is referred to Deliverable 1.1 for an overall reporting of the survey on obstacles among climate service providers and users, and to Deliverable 1.3 for details and user appreciations of the data infrastructure for climate service generation and provision.

1.3 Structure of the report and some key terms

The report consists of four main parts A-D, plus a set of annexes (1-8):

A. this introduction

B. chapters 2-5, discussing business models and resourcing, presenting interim conclusions

C. chapters 6-9, discussing quality assurance and presenting interim conclusions

D. chapters 10 and 11: presenting a synthesis, including interaction effects as well as conclusions and implications for following work packages

Parts B and C are based on literature review, on results from the survey conducted in Task 1.1 (see also Deliverable 1.1), and on interviews with diverse climate service providers, and climate service users.

Without further clarification several terms in the report may be subject to different interpretations depending on the background of the reader. We refer to the Glossary of Terms at the beginning of the report for interpretations applied in this report.

The term *climate services* is as such subject to multiple interpretations. In the Glossary we provide compact descriptions for the main types relevant for this report. On the one hand this means that climate services can encompass more than 'just' climate data, e.g. they may entail advice, non-climate data, training, etc. On the other hand **in this report, and in EU-MACS in general, we consider that both seasonal and long-**

term climate services are relevant, where seasonal may include to some extent also sub-seasonal forecasts. For national and international public bodies engaged in the provision of meteorological and closely related services these definitions can be important, as such agencies tend to operate under strictly delineated assignments of their service area(s), with implications for the allowable scope of funding, public good status, competition regulations, and exclusive rights and duties related to emergency situations.

This deliverable concerns both providers and purveyors of climate services, currently supplying or re-using climate information and data. For the scope of this document, we attributed to "climate services" a broad meaning. This covers the transformation of climate-related data – together with other relevant information – into customised products such as projections, forecasts, trends, economic evaluations, assessments and analyses, counselling on best practices, development and co-production of solutions and any other solutions that may be of use for the society at large. As such, these are products and services aimed at supporting adaptation, adaptation issues in mitigation, disaster risk management activities, and coping with climate variability in current and future climate.

As already referred to above, even though there is an emerging and growing – genuine – market for climate services, hitherto the greater part of climate service activities is not delivered though transactions on a market for climate services. Instead a good part is based on tendered research grants, organised as project work. On the other hand a part of the climate service delivery is designated as public good and used free of charge. Furthermore, a part of the climate service activity is hard to observe due to internal delivery within or across public sector organisations. As indicated it also important to realise that a very substantial part of the activity has more the character of research, product or process development, or has a piloting character. Therefore, next to the term '*climate services market*' (which has a specific meaning in economics, see glossary) also the term '*climate services field*' is used, which intends to capture all climate service relevant activity.

In the climate services field various actors can assume more than one role, i.e. many climate service providers, which are not NMSs, are also users (acquiring basic climate data). Other users, e.g. some public agencies, can also be purveyor, i.e. sharing climate services with others in the same region or public sector. This is also explained at length in D1.1. There are alternative ways to categorize actors.

PART B

Resourcing and Business Models for the Provision and Use of Climate Services

2. SETTING THE SCENE FOR CLIMATE SERVICES

2.1 The demand for Climate Services in the European Landscape

Considerable progress has been made in recent years regarding climate services. The recent efforts aimed at bridging science and innovation, have opened a new window of opportunity, moving climate information out of the "Valley of Death" (Brasseur & Gallardo, 2016). At European level, several initiatives contributed to stimulate the growth of a community of climate services providers and users by "enabling market growth, building the market framework and enhancing the quality and relevance of climate services" (European Commission DG Research and Innovation, 2015). Despite the plurality of definitions throughout the last two decades, climate services assumed the role of supporting tools for climate-informed decision making (Board on Atmospheric Sciences and Climate, 2001). Recognized as crucial products in 2009 (World Climate Conference-3), climate services were originally developed using a top-down approach, mainly focused on weather forecasting and risk assessment (Brasseur & Gallardo, 2016). Given the interests and inputs provided by universities and research centres, climate services have only recently employed a bottom-up approach, covering a wider spectrum of multidisciplinary fields (social vulnerability, resilience and impacts). In terms of sector orientation, the European and global landscape has focused on some priority areas, mainly agriculture and food security, disaster risk reduction, health and water (European Commission. Directorate-General for Research and Innovation, 2015). Over time large companies and key players have included in-house departments to deal with climate information and to promote climate-smart services and products (e.g. Allianz GI and Ernst&Young). This enlarged the spectrum of action towards other sectors, such as energy and finance.

After years of promotional activities at European and global level, it is now legitimate to assess whether there exists a market for climate services. Companies and entities are producing technologies and information that require innovative business models to reach the most interested stakeholders. The increasing demand for customized climate-related products, services and information is necessitating the theoretical underpinning of adequate business models and the definition of their role. According to previous research, these serve not just as innovation enhancers (Boons & Ludeke-Freund, 2013; Chesbrough, 2010), but typically as tools to boost the transition towards a more sustainable future (Hansen, Grosse-Dunker, & Reichwald, 2009). Business models may function as market devices (Doganova & Eyquem-Renault, 2009), but also as links between production and consumption (Long, Blok, & Poldner, 2016; Boons & Ludeke-Freund, 2013) and as support in overcoming barriers associated with the development phase of a product or service (Chesbrough, 2010).

Part B presents the findings of Task 1.2. In particular, Part B identifies the strategic framework of the considered climate services, the network of interested stakeholders involved and their interactions throughout the value chain. Finally, this deliverable provides meaningful insights on the financial structure of climate services using qualitative information.

We start in Chapter 2 with a comprehensive literature review. This helps defining what business models are, their core components and their role as market triggers. We then focus on business models for sustainable innovation, as climate services appear often to be cast a subset of or contribution to sustainable innovation. We highlight those concepts that have the capacity to influence the development of CS provision. Finally, the literature review identifies the main gaps in the literature and the role of contributions this research in filling them. In Chapter 3 we introduce the main types of CS providers in conjunction with the set-up of the interviews. We summarize the findings of the interviews in Chapter 4 while referring to the four building blocks of the business model introduced in Chapter 2. In Chapter 5 we distil

2.2 Business Models: the four main elements

By business models we mean the "representation of a firm's (and also a public services producing organisation's) underlying core logic and strategic choices for creating and capturing value within a value network" (Shafer et al 2005). The **value network** is the operational space of a specific firm and includes the full range of stakeholders involved in the business activities: clients, shareholders, suppliers, but also distributors, the civil society and coalitions (Shafer et al. 2005). Four key components, together spanning a business model, are distinguished within this network: (1) **the sample of strategic choices (value proposition)**, (2) **the creation of value**, (3) **the network** and (4) **the value detainment**. The first component, the value proposition, outlines how the value of the service is created and how it responds to end-users' needs. In his 'The Rise and Fall of Strategic Planning', Mintzberg (1994) defined "strategy" both as a backward and a forward-looking concept. In other words, strategy can be viewed as a set of choices made over time or as a plan that provides direction. The business model reflects the choices and their practical implications.

The creation and detainment of value, instead, highlights the ability of a firm to generate substantial value in a disruptive way that helps the company being differentiated from the competition. This can be achieved through innovative in-house core competencies, or through their unique integration process (Shafer, Smith, & Linder, 2005). Business models are then "market devices" (Doganova & Eyquem-Renault, 2009), which help shaping innovation by being intermediary between different stakeholders and final users. This is an important point in the context of climate services, because it helps overcoming barriers and reaching those who need climate information the most (Vaughan et al 2016). In particular, business model innovation, rather than product innovation itself, has been proven to be able to counter serious bottlenecks with the development and diffusion of sustainable technologies (Chesbrough 2010; Long et al 2016).

The fourth element of a business model is the network in which the company operates. In the context of climate services, this entails the definition (and classification) of stakeholders and users. The establishment of climate services has been for a long time mainly following a top-down approach: a wide range of products and services was created without questioning on the actual needs of those interested (Brasseur & Gallardo, 2016). This tendency of supply driven behaviour can be at least partly explained by significant economies of scale and scope of many climate services (Anderson et al 2015), making it relatively easy and low risk to extent a service portfolio. However, research has shown how relevant the involvement of final consumers is, starting from the design phase of a climate service (Vaughan & Dessai, 2014; European Commission. Directorate-General for Research and Innovation, 2015; Vaughan et al 2016). The network, in which the company or the organization operates, comprises all the stakeholders involved: suppliers, providers, partners and final users. Any of these parties interact with the firm, creating a complex system that defines the company's business model (Shafer et al 2005).

The definition of the business model is not restricted to the online sphere, but rather extended to various typologies of an organisation. Indeed, research on business model is categorized by three main streams (Wirtz 2011). The first belongs to the dot-com era and tackles the role of technology in the internet boom. Within this context, firms focused on web-based products or services, generating "e-business models" (Chen, 2003). The second one considers business models as a tool for strategic management, able to boost the company's position along the value chain. Here, the main point of interest is the process and the productivity enhancement factor that a business model is able to provide (Tikkanen et al 2005). Finally, the third stream of business model literature emphasizes the role of strategy by stressing the relevance of market competition (Chesbrough 2010). Whenever a company's product is not disruptive compared to its competitors, the business model constituting blocks can serve as enhancers of market strategies. Therefore, "a business model is the direct result of strategy, but it is not itself, a strategy" (Casadesus-Masanell & Ricart 2010). Business models are another source of competition, separate and complementary to the value propositions (Casadesus-Masanell & Ricart 2010).

Business models can serve two types of innovation, being (1) *incremental*, building on existing products or services, and (2) *disruptive*, which creates a whole new reality (Shilling 2008). In the context of climate services, the two are helpful in supporting the growth of a highly significant market. Climate services are not just crucial in supporting decision-making, but they also provide educational value, by enabling the stakeholders to share best practices, protocols, data and guidelines (Brasseur & Gallardo 2015).

2.3 Business Models for sustainable innovation

In the first place climate services, in the form of long term projections and supporting information, are conceived as facilitating adaptation and mitigation, by timely producing, translating and delivering meaningful climate data and knowledge for decision-making purposes (Board on Atmospheric Sciences and Climate, 2001). In addition so-called seasonal projections represent another branch of climate services aimed operational and tactical planning in private and public sectors, for which seasonal variation in meteorological conditions has consequences for costs and/or sales (which can be understood as adaptation to climate variability). In summary, climate services can be input for coping with **climate change** (through adaptation – including adaptation aspects in mitigation), as well as input for coping with **climate variability** (in current and future climate).

Traditionally climate services were purely based on historical observations. Some climate service products are still closely related to the 'traditional' product, whereas 'mixed' products are also possible. From a climate service product point of view there can be all kinds of economies of scale and scope in the generation of the building blocks of the various types of climate services. On the other hand various CS users may need or already use CS products for different time scales. Using one type of CS may pave the way to elicit a user's demand for others. Yet, progress in climate modelling starts to blur strict categorisation. Some CS providers refer to 'seamless climate prediction' (See also Chapter 9). All in all sustainable innovation in the context of climate services should be understood to (1) facilitate greenhouse gas emission reduction, (2) avoid or reduce other environmental deterioration, and (3) promote resilience. This is sometimes referred to with the catch word '*climate proofing*'.

Needs-based climate services – as in the tradition of 'needs based approaches' – are particularly useful to assess and manage climate risks, especially for the most vulnerable areas in the world that must cope with the negative consequences of climate change (World Meteorological Organisation, 2011). The provision of adequate climate knowledge is essential to effectively support decision makers. This involves not simply a disruptive value proposition, but also an innovative business model and a well-developed network of stakeholders (Hewitt et al 2012).

Economists have discussed at length how to drive innovation in the context of environmental issues, highlighting the urgent need to bridge science and adaptation action (Kirchhoff et al 2015) and to link climate data providers with interested users to move from "useful to usable information" (Kirchoff et al 2012). The disconnection between scientists and final users represents a huge barrier that prevents the efficient "flow from science to decision-making" (Kiem & Austin 2013). Research has explored the potential sources of disconnection (Kiem & Austin 2013; Miller et al 2008) highlighting a lack of common language across disciplines and the challenges in dealing with uncertainty, as the most persistent and potentially harmful elements. Therefore, even though information is available, end-users may not appreciate it because of the disconnection they experience with science. Climate services have the intrinsic potential to overcome this barrier by engaging the involved partners (Brooks 2013) in a constructive and trustful dialogue that matches the supply and demand side (Dilling 2007).

Literature on business models for climate services is scarce and relatively new in the research arena. A common approach is the use of case studies in various sectors to highlight challenges and opportunities, but the theoretical underpinning of the market (mal)functioning and related mechanisms is still poorly developed. However, there exists a wide body of research concerning business models for sustainable innovation. According to Larsson (2007) sustainable innovations can be defined as "innovations that are taking into account environmental, social and economic considerations in their development and use". Given the global nature of climate change and its implications for human beings, we can consider climate services as part of the 'sustainable innovation' family. As for any type of innovation, business models are critical for their success (Long et al 2017). A key contribution to the literature on business models for sustainable innovation is provided by Boons and Ludeke-Freund (2013). Within the concept of "sustainable innovation", the authors include three components: technological, organizational and social. The sustainable business model with emphasis on technological innovation, play the role of market devices and they allow overcoming both internal and external barriers to marketing. On the organizational level, business models shape the processes within a firm, implementing alternative paradigms while connecting stakeholders and users. Finally, sustainable business models tackle the social value of innovations and maximize the collective utility. Therefore, they have impact with a purpose.

The analysis of existing literature suggests that sustainable innovation tends to disregard the core elements of business models and to leave the revenue model unspecified (Boons & Ludeke-Freund 2013). Therefore, a proper business model conceptualization may help bringing those neglected elements in place and enhancing the potential of sustainable innovations, including climate services. Interestingly, business models act as signals and mediators within a given market, while positively impacting on society (Doganova & Eyquem-Renault 2009).

2.4 Climate Services: an own class of sustainable innovation

Solving the complex societal challenges of climate change and climate variability requires accurate, reliable and timely information to bridge science and policy-making (Kirchhoff et al 2015). Research has already proved the benefits of multidisciplinary knowledge production to enhance decision making processes and ultimately collective utility (Cash et al 2006; Kiem & Austin 2013; Kirchoff et al 2015). Another set of climate services focuses on better adaptation to climate variability as such or in conjunction with climate change. For this type of climate services apply similar challenges regarding the bridging from science to information directly suitable for decision making. Climate services have the potential to solve this disconnect and to serve as bridges between the climate community and a range of diverse users. By relying on existing research from climate and related sciences, climate services deliver products and services tailored to the needs of customers, users and stakeholders involved in social sciences or in specific applicative sectors, such as energy or agriculture (Vaughan et al 2016).

Despite the increasing efforts in coordinating and standardizing climate services over the years, survey results among users and stakeholders reveal a still poor connection between providers and users (EU-MACS Deliverable 1.1; Vaughan et al, 2016; European Commission DG for Research and Innovation, 2015), the inadequacy or absence of business models adopted by climate services, not always adapted to private users' culture (Brasseur & Gallardo, 2016) and a certain information asymmetry that disadvantages unequally some cultural contexts than others (Vaughan & Dessai 2014). Finally, a proper, tailor-made and effective communication is often cited as one of the major challenges to push for the development of climate services market (Vaughan et al 2016; European Commission. DG for Research and Innovation, 2015; Global Framework for Climate Services, 2016; World Meteorological Organisation, 2011; Brasseur & Gallardo, 2016).

While mitigation practices found a relatively successful window of opportunities so far (Brasseur 2015), the market for adaptation is promising, but largely still in an early stage of development. This is due to the efforts adaptation requires, in terms of time and finance (Jacob 2015) as well as legal framing (chapter 8 of this report; EU-MACS Deliverable 1.1). On the other hand, due to the hitherto large challenges to infer meaningful signals above ~40^0 latitude in Europe, seasonal climate projections are a quite new product for coping with climate variability. Furthermore, users typically require specific, accurate and measurable information that can be adapted to their specific needs (Vaughan et al 2016). The private sector internalizes climate change and climate variability into the core business to assess the challenges and opportunities it may bring and its impacts on costs and sales (Brasseur 2015). Business models for climate services must take these needs into account.

In terms of governance, climate services are developed by mainly four classes of agents[1] (Jacob 2015):

i) **Meteorological organisations (NMS)**, currently extending their services. These institutions are typically data-driven and provide strong infrastructures and highly developed observation platforms;
ii) **Universities and public-private research centres**, usually operating on a multi-disciplinary basis. They often comprise social aspects as added values to the climate-related scientific ones. Given their mandate they are not profit-driven, but instead contribute strongly to the research arena;
iii) **Expert organisations in the private sector**, with limited or quite focused (e.g. hydrology related) experience on climate, while strongly connected to the clients. These types of actors tend to have more commercial skills, including clearer product profiling.
iv) **Ad-hoc organisations** initially launched as partnerships. They enable cooperation of a wide expertise from climate modelling to impact assessment.

The presence of such diverse players within the same potential market poses challenges in developing adequate business models for climate services. The panorama of users is equally diversified and spans from technological advanced SMEs to municipalities and even states. The adoption intake of climate services is therefore conditioned to overcoming some key issues, already identified in previous literature on business models for sustainable innovations (Long et al 2016): the clear definition of how users will take advantage of the innovation and how easy it is, but also the level of education stakeholders have in dealing with the uncertainty and the complexity of information (Vaughan & Dessai, 2014). Finally, the climate services market is peculiar in the identification of stakeholders involved. In fact, many agents can both demand climate services and supply (further processed) climate services. I.e. each agent can be a provider, purveyor or user of climate information at the same time. This additional source of complexity increases the challenges of an adequate theorization of the optimal business model for climate services.

In this respect the notion of the **value chain** is helpful (see chapters 6 and 7, and Annex 8; Anderson et al 2015), albeit that as compared to for example weather services the value chain is more complicated (i.e. less 'linear'). Of the above identified types of agents in the CS market NMSs are strongly represented in the upstream part of the value chain, partly because of their legally designated position with respect to observation networks and basic weather services and warnings. As climate services are equally subject to economies of scale and scope as weather services (Anderson et al 2015) NMSs are in an advantageous

[1] . In EU-MACS Deliverable 1.1 a similar categorisation is presented, however that also identifies expert organisations in the public sector (e.g. the National Road Administration advising regions).

position to develop climate services from the point of view of incremental costs and ability to diversify. The next group (public sector and universities) could be cast as predominantly mid-stream whereas the next two groups are typically operating more downstream in the CS value chain.

It should be realized that in general the greater part of the value added potential of climate services is realized in the downstream part of the value chain (Perrels et al 2013; Anderson 2015), which associates stronger with other skills and facilities than climate knowledge and data proper. This hints at the possibility for different business models, provided a chosen business model is commensurate with the position(s) in the value chain where the climate service product belongs. Indeed a recent report on open data based services (European Data Portal 2017) indicates that quite a variety of business models exist, while one CS provider can operate several business models for different CS products.

3. MARKET CONDITIONS ON THE CLIMATE SERVICES MARKET

3.1 Methodology: identifying the main players by type

The review of the relevant literature helped framing some of the main components of business models currently in use in the field of climate services. Given the relatively recent nature of climate services, the design phase of their business model represents a tremendous opportunity, but also a demanding challenge. In the start-up phase, every organization, firm and project operating within the climate services market, must set up an efficient system to generate and share value, while operating in a well-established network of customers and stakeholders.

The growing climate services market constitutes a wide variety of actors that design and implement research and innovation actions. Therefore, a still large number of public research institutions and higher education bodies are currently working to develop innovation oriented research projects. These are typically not described by a private sector business model. However, non-profit organisations equally pursue the mission of generating and sharing value, seeking to achieve a broad set of social goods for society. Therefore, even if the application of a pure "business logic" may be controversial when it comes to research organisations, there is evidence that a peculiar form of business model is in place (Universalia, 2013). The relative immature status of the climate services field (or market) has not yet allowed for a comprehensive evaluation of business models in use.

To fill this gap, we run an original data collection, by engaging with relevant stakeholders distinguishing between:

I. Publicly-funded projects
II. Private sector
III. Co-Production Partnerships (public-private or public-public or private-private)

The first category includes relevant EU projects (both ongoing and completed), research performing organisations, universities, as well as regional and locally funded projects. The second is a set of private companies and for-profit entities. Finally, co-production partnerships include non-profit organisations and think-tanks that are currently benefitting from mixed resources. Therefore, the source of funding and, ultimately, the main class of business model employed represent the crucial determinant of the distinction between categories. Annex 1 lists the interviewed organisations.

This approach represents one of the added-value of EU-MACS Project. As already confirmed in the relevant literature, business models may act as "market signal" devices. Therefore, they may function as catalysts of diverse resources.

Given the exploratory nature of this project, we employed a qualitative approach in dealing with data. We conducted semi-structured interviews with projects and companies in the sample. Instead of launching a proper survey, we instead decided to engage in a participative approach to capture the constituting elements of business models and to complement the knowledge already gathered in Deliverable 1.1. We followed core guiding questions (see Annex 2) to drive the conversation and to maintain consistency throughout the sample.

Limitations of this approach include – among others – the lack of a quantitative assessment and a relatively poor stakeholder analysis. Indeed, it was not possible to run a statistically significant Social Network Analysis in Task 1.2. However, findings of this deliverable affirm the key messages of Task 1.1 (see

Deliverable 1.1) and collect very useful qualitative information, which cannot be picked up in surveys. We conducted a semi-structured telephonic interview with each interviewee.

Interviews lasted approximately thirty minutes each and provided knowledge on four main components:

- The set of strategic choices (value proposition)
- The creation of value
- The value network and the value detainment
- Barriers and difficulties encountered and/or solved

Analysis of gathered data, involved thematic coding. In particular, typical and frequent replies were coded, as well as any relevant piece of information that was critical to understand the functioning of the business model used by the stakeholder. Coding passed through iterations and consistency checks. Codes were grouped into main themes[2] and were aimed at detecting critical issues.

3.2 Public funded projects and institutions

A wide range of actors and projects are operating in the emerging climate services market. Public actors, such as meteorological organisations and research performing institutes, were the first to value the climatic information and to extend their services beyond pure weather applications. We performed a bibliographic research to detect the main actors operating in the market. We first restricted the sample of this work to European projects funded in a twelve-year period (2005-2017) under different strategic programmes. We consulted the Community Research and Development Information Service (CORDIS) platform, the European Commission's portal that collects updated information on past and ongoing funded projects. To perform our bibliographic research, we used the CORDIS search engine. We looked for projects by inserting the key words "climate services" under any programme, subject and country. Given the broad spectrum of available choices, we included all climate services providing a service or a set of services[3]. We downloaded a list of 153 uploaded projects[4], but we restricted our interest to initiatives with an applicative objective. This comprises practical, open-access tools, innovation actions, platforms, training activities aimed at increasing public and private stakeholders' engagement in climate services. We did not include theoretical and explorative research (e.g.: Marie Sklodowska-Curie Research Fellowship Programmes) and updates of already existing materials. The so-compiled database contained 71 projects, 16 of which were specifically related to EU-MACS core sectors (urban planning, finance and tourism). We built a database including information on Content Type, Record Number, Acronym, Title, ID, Teaser, Programme, Start Date, End date, Language, Available language, Last update. We added the fields of expertise, a PDF descriptive file presenting the project (if any), the project website and contacts of the reference person.

We also consulted two other major sources to complement CORDIS information: the Copernicus Climate Change Service (C3S) and the Climate-ADAPT database. Regarding the former, we focused on the section dedicated to "providers", while for the latter, we used "climate service" as keyword to perform the research for consistency reasons. We found 36 climate service-related projects within Climate-Adapt database, 28 of which considered as application oriented. In this case, the application is provided by the generation of an online platform, or by a dissemination plan that aims at spreading knowledge. In the Copernicus database, we found eight providers, all included in the "applicative" category.

[2] The full list of codes can be found in Annex 2
[3] As by EU Roadmap for Climate Services
[4] Projects at 17/01/2017

We also run an extensive research on other resources[5], with a more global and extra-European scope. We employed the same keywords used in CORDIS database for consistency, exploring data for the following: The World Bank, the Global Framework for Climate Services (WMO-GFCS), the CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS) and the OECD Climate Fund Inventory Database. Despite some interesting examples and case studies, we were not able to collect the information CORDIS was providing in an organic way. Therefore, we confined our analysis to the European market and we maintained the previously compiled database as our core input.

Given the exploratory nature of this project, we employed a qualitative approach in dealing with data. We approached the Scientific Coordinator of each project and we conducted a semi-structured telephonic interview with them. Interviews lasted approximately thirty minutes each. We interviewed nine projects in a period of 90 days.

3.3 Private sector actors

The inclusion of private sector players is crucial to assess the market for climate services, its barriers and opportunities. We asked to a sub-sample of experts in the field of climate services to provide suggestions regarding the private companies and businesses operating with climate-related data. Experts were selected among the universe of publicly-funded projects mentioned in the previous section. We managed to interview eleven actors. The sub-sample includes:

- Private companies providing environmental and engineer-related services
- Insurance companies
- Asset management firms
- Global strategic consultancy firms

In terms of geographical coverage, we interacted with European stakeholders, distributed between the Mediterranean area (Italy and Spain) and the Central European one (Austria, Germany). The geographical scope of their operations, instead, varies depending on the actor and spans from local actions, to regional, national and supranational ones. Finally, the main sectors serviced by private CS providers are oil and gas (exploration and refinery), energy supply (electricity, district heat, natural gas), renewable energy, financial services, construction and urban development, compliance and regulatory counselling.

As in the publicly-funded projects case, the explorative nature of this work required a more qualitative methodology. We contacted the Management team, or in alternative, a deputy person to set an online or phone conversation of approximately 30 minutes.

We aimed at diversifying as much as possible the sub-sample of private sector actors. However, this sub-sample must be considered as statistically not representative of the climate services panorama. Indeed, it represents a first documented attempt of portraying the comprehensive landscape of stakeholders interested in the topic.

3.4 Co-production partnerships

The co-production partnerships emerged as an interesting new organizational approach in our scans. These organisations are often public-private partnerships, and catalyse multiple stakeholders under a common goal. Yet, public-public and private-private can be encountered as well.

[5] The full list of consulted resources is included in Appendix I. All resources were lastly accessed on January, 31st 2017.

The literature and practical experiences have demonstrated that there is no clear-cut definition of Public-private Partnership (PPP). First appearing in the 1990s, the use of PPPs abounded tremendously throughout the last three decades (Weihe 2009). The PPP knowledge Lab identifies these partnerships as long-term contract between a private party and a government entity, for providing a public asset or service, in which the private party bears significant risk and management responsibility and remuneration is linked to pre-specified measurable performance.

The common nature of climate requires the participation of diverse actors and the convergence of multiple interests towards a mutual benefit. Therefore, climate services represent an unprecedented opportunity to build medium and long-run agreements and to boost climate adaptation and mitigation actions. To some extent, European initiatives (such as Horizon2020 Programme) are already pushing for PPPs by enhancing the role of consortiums in delivering “climate-smart” solutions.

In the context of climate services, this form of co-production partnerships is rather to be conceived as a new strategy of cooperation. In particular, Public-Private Partnerships for Climate Services they are built as initiatives where funds and knowledge are proportionally shared between the public and private actor to achieve mutual benefits and promote innovation actions in climate services. They may boost product development and services delivery, but also knowledge formation. They boost innovation through the provision of demand-driven services, aimed at promoting innovative solutions. On a legal basis, they may be not-for-profit entities, functioning as multi-stakeholder think-tanks.

Successful examples of it already exist. The UK Department for International Development (UK-DFID) launched in 2015 the Climate Public Private Partnership (CP3) programme committing £130 million, £110 of which is invested in two commercial private equity funds (UK Government, 2015). Despite a lack of a common framework in regulating the existing PPPs, their role in shaping climate services in growing over time. A careful evaluation of partnerships in the field of climate services has also been pointed out in the literature as a requirement for a better market understanding (Vaughan & Dessai 2014).

We contacted and interviewed three successful examples, currently operating worldwide in the field of adaptation, finance and insurance. On a legal basis, they are not-for-profit entities. Their members are both public and private entities, working together under a multi-stakeholders’ umbrella.

4. BUSINESS MODELS OF CLIMATE SERVICES - SUPPLY SIDE

4.1. Involved actors: providers, intermediaries and re-users

The analysis we conducted comprises a wide range of actors working in different fields and operating with climate-related data as providers, but also as intermediaries (purveyors) or re-users. The data we collected through the semi-structured interviews helped us assessing the differences between public and private actors currently operating in the climate services market. Furthermore, we also covered a separate and increasingly relevant category of actors that uses co-creation and co-production of information as the basis of their activities. This is a form of Public-private Partnership, where stakeholders come together to guarantee a new product or service to the market.

Public funded projects included in our sample are mainly working in the fields of water, energy, urban planning, energy-efficient buildings and agriculture. They were funded by the European Commission (Horizon2020, FP7), Climate-KIC, national, regional and local resources (National adaptation plans, ad-hoc regional budgets). In terms of activities, the publicly-funded projects we interviewed focused on the provision of:

- Climate projections and Climate observations (global models)
- Climate projections (downscaled models at regional and local level)
- Impact evaluation (combining socio-economic or agronomic data)
- Methodology development (indicators and/or protocols)
- New product development (e.g.: sensors)

Private actors recently started engaging in the climate services market. Companies are increasingly valuing climate data and are including new products and services in their core businesses. In two specific cases, Climate Change Departments were set up to develop new methodologies using climate and weather information as inputs.

We interviewed nine initiatives working in the following sectors:

- Insurance and re-insurance
- Financial services (asset management)
- Oil and Gas
- Energy
- Strategic consultancy
- Environmental consultancy

They are located in Southern Europe (Spain and Italy), in Central-Western Europe (United Kingdom, Germany, the Netherlands) and in Finland. Some of the collected contributions belong to firms operating worldwide. Their experiences started approximately almost twenty years ago and saw *"unprecedented"*[6] growth after the Paris Agreement was approved. The services delivered are user-tailored and demand-driven. The wide range of expertise and ability to intercept users' needs is boosting the CS market.

In terms of co-production partnerships, we identified two key projects while interviewing public and private sector projects. They are functioning as multi-stakeholder platforms and they rely on innovative technical infrastructures which enhance climate-informed decision-making processes and have the strength of overcoming some of the institutional and economic barriers already analysed[7]. The projects interviewed

[6] *Source*: interview with Amundi

[7] See Deliverable 1.1, section 3.5

are both operating in the financial sector, one is primarily focused on green finance and the other on insurance.

4.2. Encountered prevailing business models

Based on the pricing strategy and the use of open data, we identified four main typologies of business models within the sample:

i) Freemium

ii) Demand-oriented

iii) Supply-oriented

iv) Open source

The **Freemium** concept includes a free-of-charge set of features and an additional charged component. During initial usage stages, the users can access the platform of the service without paying any fee. The free part can be limited in time or in content, depending on the providers' choices. Input information are both open data and client-specific information, with different pricing strategies.

The **demand-oriented** business model is a consultancy-like strategy: users and providers interact and agree on a set of deliverables and objectives. Here, the co-generation process is crucial to assess where needs, knowledge gaps and requirements are and to elaborate the most appropriate plan to achieve the results.

The **supply-oriented** business model is characterized by a dominant position of the providers, which tend to showcase and offer a set of products and services to – by the provider perceived as – potentially interesting users. This strategy is valuable in very early market stages and represents an opportunity to break the entrance barriers and stimulates interest around climate services.

Finally, the **open source** approach is more like a strategy, rather than a business model per se. Providers cooperate in the form of partnerships with other agents, complementing their knowledge gaps. Also, providers may generate revenues from open source software or its components, by selling them as a software-as-a-service (SaaS). Instead of providing advisory services, data or modelling outputs to the client, the provider supplies the tool required in the decision-making process.

In some cases these business models were consciously selected (notably in the case of Freemium and demand oriented approaches), while in other cases the encountered model is more or less a default extension of existing service practices of the organisation or is based on broader based views regarding the societal function of climate services (such as in the choice for open data). Last but not least, we reiterate that a significant share of the encountered 'climate services' is not (yet) in an operational service delivery stage, but either in a development or piloting phase. These phases may be better characterized by innovation-resourcing models, than by business models, even though a well-founded view on feasible business models as part of the innovation process can help to raise service development success rates.

4.3. General findings regarding climate services' actors

There has been considerable discussion about how to stimulate the market for climate services and to shift from the "Valley of Death" (Brooks, 2013) towards an effective commercial exploitation of products and services. Results from the semi-structured interviews conducted for this deliverable contribute to this debate by providing insights and recommendations on the most suitable business model.

As showed in Deliverable 1.1[8], six main barriers are preventing an efficient market development for climate services, i.e. political, economic, social, technological/scientific, ethical, and legal/regulatory. Throughout the semi-structured interviews, we assessed the most pressing issues for stakeholders, distinguishing between public, private and co-production partnerships. To help visualising and interpreting commonalities and differences in the sample, we created three *word clouds:* graphical representations of word frequency (figure 4-1, next page). We excluded irrelevant words (such as articles and pronouns), but also the outliers (such as “climate change”).

Public, private and co-production partnerships are all concerned about “data” and they are repeatedly mentioning “users”. However, it is interesting to notice how the language changes depending on the type of actor engaged: publicly-funded projects mention “partners”, while co-production partnerships interact with “stakeholders” and private sector agents deal with “clients”. This is a relevant shift of paradigm: depending on the interactions along the value chain, products and services are also changing, presenting an increasing heterogeneity.

Publicly-funded initiatives are normally constituted by *projects*, funded under *European calls*. The mentioned *products* and *services* are typically delivered by *providers,* also in the form of *prototypes*. Private sector, instead, presents a *portfolio* of products, especially in the *insurance* and *energy* sector. *Risk* is a crucial factor and carbon-mitigation activities are still a core component of the business model of actors. Finally, co-production partnerships incorporate elements of both the private and the public sector. The services they are delivering are not just research-oriented, but also profit-driven within a highly technological infrastructure (which may or may not be open). It is worth mentioning that both private and co-production actors are still considering *weather* as part of the Climate Services.

Word clouds are presented below: red words are shared by all actors; the blue ones are common to public sector and co-production partnerships. Finally, the purple words are the ones that co-production partnerships share with the private sector.

[8] See Chapter 3.5, Deliverable 1.1

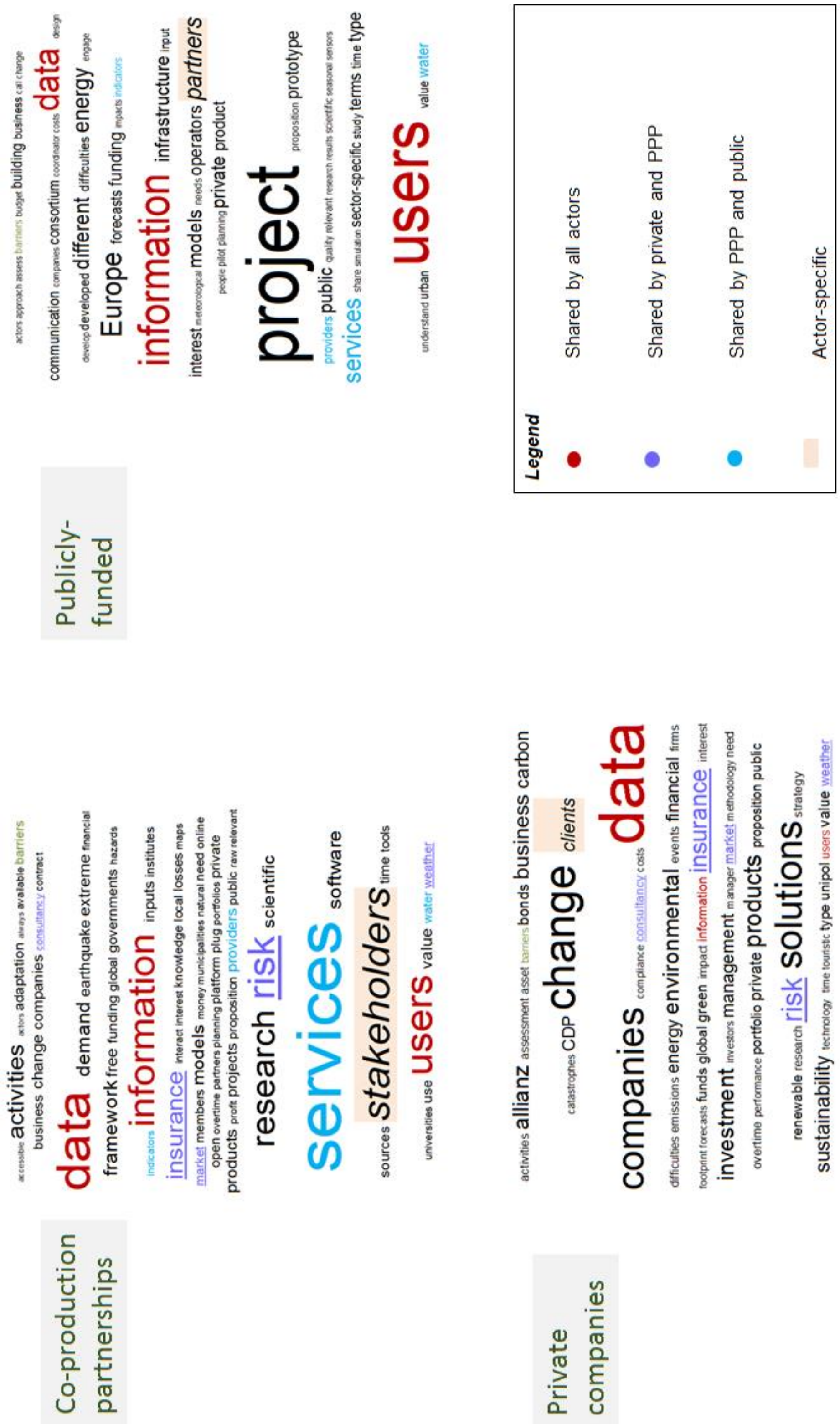

FIGURE 4-1 FREQUENCY OF TERMS BY TYPE CS PROVIDER

4.4. Towards a clearly defined value proposition

Through the exploration of the current nature and scope of climate services supply, it is possible to enable new market opportunities (European Commission, 2015) and to stimulate potential windows of opportunities. As previously mentioned, we conducted semi-structured interviews with senior management of each initiative under consideration. We aimed at detecting the characteristics of the main business model components and at highlighting barriers and difficulties in reaching their goals. We started with the identification of their value proposition, which includes the set of activities of a determined product or service and highlights the contribution of each specific initiative in generating added value to a specific field of operation.

Given their intrinsic nature, projects benefitting from public money normally respond to *Calls for Application*, *Calls for Tenders* and *Expressions of Interest* formulated by a public institution. *Therefore, they are providers of mainly supply-driven defined objectives and they have a strong research component*. They transform climate-related data into usable products and services, promoting a form of innovation that benefits society as a whole. Their ultimate goal is the advancement of climate services for the common good and they are not driven by profit in delivering the outputs of their activities. They target practitioners, academic communities, municipalities and decision-takers. Furthermore, they aim at creating a science-informed environment to simplify policy making. This is also reflected in their legal status: they are all *consortia* of research performing organisations (such as national meteorological institutes (NMS)), universities and – in some cases – private companies or foundations.

Some of the initiatives succeeded in delivering prototypes that were commercialized afterwards even in parts. These were initiatives that had previously interacted with specific and previously identified users. However, the majority of the projects in our sample did not survey potential users of the service in the proposal writing phase and they instead undertook a top-down approach on average.

Providers within the public sector self-identified in almost every interview as both providers and users of climate-related information. Even though they are supplying new models, protocols and methodologies, they strongly interact with other providers in the landscape. They tend to re-use already existing data and to collect new one. They cooperate within and outside the consortium they belong to, sharing knowledge and best practices that enrich their expertise. The value proposition is often not strongly developed in these cases. Even though there may be aspirations to eventually deliver an operational climate service, often actual achievements remain in a proto-phase, which may lead to take-up later by some consortium members or third parties. In the background the project organisation form, being terminal by definition, constitutes an obstacle to transform to continued activity.

In one case, we interviewed a Climate Services publicly-funded project that self-identified as purveyor and used data from other publicly-funded organizations. Its non-profit status increases the explorative freedom. The main added value comes from advising municipalities to better adapt to climate change especially in zoning related issues.

Private sector providers are, instead, more diverse in terms of expertise, targeted users and value proposition. The insurance sector is the most advanced at the moment and operates on five main streams:

- Insurance products
- Renewable energy project finance
- Financial products for the retail market
- Standards development and scientific research
- Climate risk assessment

The first one encompasses a wide range of products: performance guarantee insurances, insurance products against "bad weather" and re-insurance. Climate data are supplied by private sector companies and serve as inputs for new products development. "These services are crucial for use because they shape innovation within the insurance sector and boost an on-going transformation towards a more consulting approach to the client"[9]. Given that climate change is having an impact, direct and indirect costs of insurance and re-insurance are growing, too. Therefore, the creation of innovative products is not just a mean to fight against a global phenomenon, but also a business matter.

While climate data are relevant for protecting against natural hazards and adverse weather, they also serve as inputs for renewable energy project finance. Private sector companies have now the capacity to forecast the costs of maintenance and to estimate the insurance premiums of renewable energy plants[10]. The in-house capacity and expertise is growing even in terms of natural disasters: firms are collecting data on catastrophes and hazards, computing economic losses and global effects of a localized bad weather event[11]. This is particularly relevant for multinational companies operating in developing countries increasingly exposed to climate risk. "We are working on improving the way we connect the data and to understand better the concentration risk. Insurance can play a significant role in boosting the way we study global value chains, especially those highly affected by climate change"[12].

As general trend, private sector stakeholders are working on Climate Change looking at different topics and covering carbon-related issues as part of their scope, too. This is particularly relevant to tackle the inclusion of this service in further market development. Due to compliance and demand-driven requests, environmental consultancy firms, large consultancy firms operating worldwide, but also asset management, are considering Climate Change in a range of sustainability-related projects. The entry point of their market, indeed, is not simply the elaboration of climate-related data, but rather energy, energy-efficiency, carbon footprint ones.

Asset management firms are delivering a wide range of products starting with the provision of research and standards development. Working in cooperation with the academic sector, Amundi succeeded in creating a new methodology aimed at analysing the financial risk linked to global warming. Their approach gave birth to a new type of indexes (the MSCI Low Carbon Indexes, https://www.msci.com/msci-low-carbon-indexes) and to innovative financial products:

- An Exchange Traded Fund (unique in Europe so far)
- Two Index Funds

Another example is the Climate Disclosure Project (CDP, not interviewed) which collects information both with respect to mitigation (carbon tracking; measures) as well as adaptation (climate risks; measures) of both companies and cities worldwide. A part of the data is freely available, other – comprehensive in-depth – datasets are provided against charge. CDP helps organisations to better learn from past performance of the own and comparable organisations (benchmarking), while it also aims to promote *public disclosure* of carbon intensities (and hence climate policy vulnerability) and of climate change risk exposure.

Environmental consultancy companies are also using climate-related information as both providers and users of climate information. We interviewed two fast-growing SMEs specialized in one or more specific sectors. They offer consultancies on:

[9] Source: Interview with Maria Luisa Parmigiani, Director of the Sustainability Division of Unipol Italy
[10] Source: Interview with Simone Ruiz-Vergote, Head of Allianz Climate Solutions GmbH
[11] MunichRe, Allianz Climate Solutions, FloodRe
[12] Source: Interview with Simone Ruiz-Vergote, Head of Allianz Climate Solutions GmbH

- Definition and implementation of appropriate norms
- Strategic environmental evaluations
- Monitoring activities
- Scientific research and incubation of environmental start-ups
- Climate risk assessment

While performing impact evaluations, the interviewed environmental consultancies use both primary and secondary data, according to the specific needs of the project. They gather secondary information often from the UNFCCC and the IEA and is combined with client's context specific metrics. Clients are local, regional and private entities and they may use consultancy services also for normative mandatory requirements. In fact, regulation enhanced clients' interests and duties in environment and climate change and opened new business opportunities, widening the spectrum of available services.

Also multinational strategic consultancy firms entered the market by supplying climate-related advisory services. We distinguished between companies with and without a strong engineering component. Those that are more focused on pure strategy and management, include climate change in their ESG (Environmental, Social and Governance) Division. They analyse climate change as part of a holistic approach that look at socio-economic and environmental sustainability. They may use sustainability balance sheets and sustainability reports. They are primarily operating in segments of the energy sector (oil and gas, electricity, renewables). They advise their clients on norms, regulations and policies in place. However, they are moving towards a more diversified range of consulting services, allowing for further windows of opportunities in the next future.

Consultancy firms operating with a solid engineering base tend to establish (flexible) teams of experts for using or interpreting climate data for advisory and consultancy purposes. Results from our interviews suggest that services offered are continually growing and have been evolving over the past decade. They are mainly concentrated in the building and construction, energy and renewable energy sectors. They are able to advise clients future expected effects of climate change on businesses. This allows the client to be better informed and to take into account more variables when taking a strategic decision.

While the demand from clients is growing, so is also the expertise in collecting and analysing data of the climate services providers. For some sectors the market is still young and under development, while others have already witnessed disruptive changes. Regulation may serve as market booster to enhance competition and include more players with diverse competences and approaches.

The success of the projects we included in the sample is mainly driven by a strong interaction between private and public actors in filling the existing gap in providing climate services. They can count on the support of established institutions and companies and they operate in mature markets (insurance and finance). They are committed to transparency and standardization of data, protocols and tools. By enhancing collaboration for mutual benefits, they are achieving their goal of creating a vibrant community of users and stakeholders.

By providing risk assessments, scientific research and dynamic modelling, they are operating through collaborative platforms supporting public policy and private investments. In one case, the open source infrastructure of the project allows a flourishing cooperation between the public and private agent not just in sharing knowledge, but also in generating new one. They may (or not) commercialize their services (or a part of them). They rely on public money (at national or supranational level) and on private investments.

The projects we interviewed present three main strengths:

- They address the users' needs by giving them the freedom to choose the type of service among the available providers of the PPP;
- They are endorsed and financially supported by a diversified portfolio of stakeholders, reaching multiple users;
- Partners of the PPP have extensive research experience. They register high credibility and reputation.

4.5. From input to output: the data sources and the right user

In the transformation process of raw climate data and climate-related information into a functioning climate service, agents encounter a wide spectrum of challenges. All projects we interviewed agree that climate data availability and data quality increased over time. The skills and the expertise to manage this type of information are also growing. Therefore, the trend is globally positive and the market is receiving encouraging signals for the launch of an effective integrated platform for climate services. In some cases we had the opportunity to study the evolution of the market by interviewing consecutive projects. Results are promising. While some sectors are currently experiencing unprecedented growth (e.g. climate finance and insurance), others have been experiencing a more constant development (e.g. water). The dramatic growth of real-time data and high resolution technologies is incentivizing the market for climate services by stimulating both the demand and the supply.

Global engagement has also boosted private sector's attention towards climate change and climate-related topics. Therefore, policies and regulations are needed to create and stabilize the framework in which the private sector may enter.

4.5.1. Publicly-funded projects

We asked our sample of interviewees to provide information regarding their input data and their data transformation process. As mentioned before, these projects are typically organized in consortia, where normally one or more data providers are included. Therefore, input and raw climatic, meteorological and climate-related information are normally supplied internally. Whenever this has not been possible, Copernicus served the purpose. However, a wide range of projects also collected original data to compile original databases. This is particularly the case for climate services tested in pilot cities. Primary data may or may not be published depending on the degree of confidentiality. In fact, databases can contain firm-specific or site-specific energy-related metrics protected by NDAs (non-disclosure agreements). Original data collection often includes the relevant norms and regulations that impact on the project.

Forecasts, models and tools, instead, vary according to the type of projects. They may be discussed together with the potential user or can, instead, be agreed within the consortium by looking at the available competences.

Projects under this category target a wide range of users with the very same initiative, at different level. Users are normally identified in the concept phase of the action and they may vary according to the sector the consortium is tackling.

Generically speaking, the publicly-funded interviewed projects identified both private and public users of their services. The private sector user embraces individuals, corporations, SMEs and multinational firms. The public one includes:

- District level actors and associations
- Municipalities
- Regions
- Country-level actors
- Supranational regulators (decision takers and policy makers at EU and IO level)

Projects in this category provide to the users both the demonstration of the intrinsic value of a specific climate service, and they create an innovative product that may – in the future – be commercialized or further developed. This is particularly relevant if the user is a public national or supranational authority. When successful, publicly-funded climate services represent an empirical proof of their utility. Finally, some of the projects in the sub-sample, contributed to the market assessment of a given sector by providing high-quality research services.

4.5.2. Private sector actors

The private sector assumes quite a different attitude towards input data. Cooperation and mutual help in knowledge sharing is obviously not a trait of these stakeholders. Competition is still modest and the prevailing data providers (such as institutions or research performing organisations) are typically operating with different timescales and inefficient dissemination schedules. Therefore, private data providers are supplying companies, insurances and financial services stakeholders. There are some exceptions though. Out of nine private stakeholders, we registered two currently interacting with public regional data providers. Furthermore, models and climate scenarios are extracted from well-established International Organisations (e.g. UNFCCC). The cost of input data may vary. However, results from our interviews show that these can be quite substantial, especially for SMEs and small firms.

Due to their strong interaction with clients, private sector actors also collect primary data to deliver a complete climate service. This is context and user-specific. As such, information is not available to the general public and is protected by confidentiality clauses. Data on energy performances, financial losses, but also green-house gas emissions are also collected through private providers or via questionnaires and interviews.

Climate services falling in this category serve mainly private companies, typically publicly listed companies or multinational firms. In some cases, we found that they also supply consultancy and advisory services to municipalities and regional regulators. In the specific case of finance, climate services serve the retail market with active and private investors.

4.5.3. Co-production Partnerships

The nature of these climate services represents a competitive advantage in terms of data acquisition. Partners within the consortium are providers themselves of climate related information, tools, protocols and scenarios. Therefore, these projects do not face acquisition costs for the inputs. In one specific case, the infrastructure employed exploits an open-source business model. Therefore, stakeholders are sharing not just data and input, but also knowledge and expertise when creating new components of the service.

The inclusion of private sector actors within the partnership allows a better communication with potential users and creates a proactive environment to adapt the service to the clients' needs. Furthermore, one of the goals of these co-production partnerships is the standardization of data and information used in the private sector. The interaction with multiple actors creates a fertile ground to reach this objective.

PART C

Quality Assurance in the Market for Climate Services

5. COMMON PRINCIPLES OF QUALITY ASSURANCE

5.1. The context of quality in climate services

The assignment for Task 1.3 as formulated in the DoA states that Task 1.3 assesses the role and significance of quality assurance in CS in terms of juridical basis, ethical aspects (good conduct, misperceived risks), technical and administrative feasibility (standards, branding) and economic effects (very strict quality requirements may hamper market development due to extra costs and complexity). Both current practices and plausible extensions are reviewed. The work will be based on a literature review, a quick scan of CS websites, a comparison with similar information services for other policy areas (notably energy efficiency promotion), and interviews with CS providers and CS users.

As postulated in the EU-MACS study plan, the eventual purpose of climate services is risk management – risk management for the society, area, sector or organization by which the climate services are applied, while being alert on opportunities for product development so as to enrich and tailor the risk management framework. This means that the use of climate services is typically embedded in a risk framework relevant for the considered territorial or organizational body. A fundamental problem arises when the prospective CS user has a poorly articulated risk management framework, requiring a preparatory phase and/or a strong emphasis on embedding the climate information.

It merits to emphasize that risk management is to be understood broadly i.e. encompassing both the **opportunities and risks** created by climate change. Depending on the evaluation context missed opportunities can be regarded as damage as well.

Given the premise that climate services feed into a risk management process, the quality of a climate service can then be interpreted as (1) the extent to which the offered qualitative and quantitative concepts **fit** in an organisation's risk management process, (2) the extent to which embedded information transfer process achieves **capacity building**, and (3) the **accuracy** of the underlying data. The relevance of these dimensions of quality may be expected to vary according to the nature of the climate service.

The **fitness for use** can have both qualitative and quantitative aspects, i.e.:

i. Including variables that are the closest possible proxies to the effects of interest
ii. An information representation (display) that conforms with the other information use in the decision process
iii. Relevant spatial and temporal resolutions
iv. Well documented account of statistical properties of the provided data series

The **capacity building effectiveness** of the information transfer process (data, education, consultancy, etc.) encompasses (among others):

i. Ex-post satisfaction of the user with the transfer process
ii. Responsiveness of the CS supplier during the transfer process
iii. The ability of the user to absorb information and to mobilize the right resources (for given / agreed transfer process and information)

The **accuracy** can be evidenced by quantitative and qualitative characteristics:

i. Well documented account of statistical properties of the provided data series (uncertainty ranges)
ii. Historical performance of subsets of the dataset in relation to observations
iii. Well documented account of the information generation process (origin of data, and nature of data

processing steps and their consequences for uncertainty ranges and the degree to which uncertainty can be sensibly assessed)

The above set of key characteristics is meant to be *supportive* for the review process in this Task, but is *not meant to be definitive*. The review as such can generate reasons to reconsider the list.

The *scope of a quality assurance* for CS is subject to different interpretations (QA4ECV 2014; Ludolph and von Flotow 2014; Gregow et al 2016). The extent to which embedding of the information transfer is to be considered in quality assurance, is subject to discussion (Ludolph and von Flotow 2014). By embedding is meant the service elements that are complementing the information and its (technical) provision proper, such as consultancy service, schooling, and elaborate support information on how to interpret and handle provided information ('user guidance'). The challenge is that the embedding elements of a service package easily extend beyond what is usually understood by quality assurance, i.e. moving into ethical aspects as 'good conduct' or marketing features such as 'easy access' or 'quick service'. The performance on such aspects depends as much on clear product profiling as on the intrinsic quality of the service product. Furthermore, the performance on these aspects not only depends on the CS supplier, but also on the user, e.g. downplaying signals of a probably less fitting choice may result in reduced use satisfaction. All in all the embedding elements of a CS may be best assessed by client user satisfaction indicators. In this review we intend to pay attention to how such indicators relate to quality assurance and to what extent these tie in with other (non QA) management and production processes.

In the literature based on reviews of climate services (Ludolph and von Flotow 2014; Mañez et al 2014; Gregow et al 2016; Alexander et al 2017) quality assurance is usually only mentioned in relation to features of CS that need further development. In as far as there is information provided on quality it usually refers to:

- Tractability of data sources
- Tractability of data processing steps (ensemble vs individual model data; bias corrections; rescaling procedures to unify temporal and spatial scales, etc.)
- For information platforms also rating of the ease of access and ease of data selection may be evaluated, but there is no clear (practically) standardized norm in this respect

To some extent the *service experience* has been evaluated in various review studies, but there has been done little work on standardization and validation of the definition and rating of these service experiences.

From the list of considerations above 12 topics were identified (table 1 below), divided over three domains, being:

1. Inventory of current practices based on literature review, interviews, and a survey (jointly with Task 1.1) (light blue boxes in table on next page);
2. Inventory of current and emerging legal, ethical and economic factors necessitating or precluding certain choices, based on (probably scant) literature and interviews (bear in mind that also more generic legislation e.g. on public service obligations may be relevant) (purple boxes);
3. Review of implications of the current (underdeveloped) state of practices and of prospects for raising standards in conjunction with standardization – this will be tackled in the concluding chapters after having assessed the messages from the literature review, survey and interviews.

Being implications the topics 10, 11 and 12 are dealt with in the synthesis part D. Yet, topic 10 is to some extent touched upon in relation to other topics.

TABLE 5-1 IDENTIFIED TOPICS STEERING THE QA REVIEW

1. Practices regarding the information generation process – explicitly or implicitly declared (which steps included (point iii of accuracy); references to formalized procedures (WMO; ISO, etc.)
2. Practices regarding reporting on statistical properties and effects on selections
3. Practices to evaluate or indicate the fitness for (a particular) use
4. Practices regarding flexibility in spatial and/or temporal resolution and indication of quality implications
5. Practices regarding embedded CS (user guidance, advice, education, etc.) – e.g. is embedding adaptive, is it significant, etc.
6. Practices regarding ex-post user satisfaction measurement
7. Legal imperatives regarding the above practices (obligations; accountability; …)
8. Ethical guidelines on good conduct in supply and use of CS? (none; implicit; explicit)
9. Resourcing implications for rigour and application of QA
10. Prospects for standardization of the identified practices
11. Implications of current practices for use / non-use
12. Implications of best practices for supply costs

Four main types of climate service are distinguished for which the twelve topics have a varying degree of relevance, being: (I) seasonal (intra-annual) forecasts, (II) historical series, (III) multi-decadal climate change projections, and (IV) consultancy & schooling. Additional sub-classification can be applied e.g. regarding observation sources and post-processing protocols (see also chapter 7 and Annex 4). Furthermore, impact oriented climate monitoring services are emerging as an own category, encompassing elements of category I, II, and IV. Seasonal CS and historical series allow for formal verification procedures, whereas the other two can only provide information on data sources and data processing. For long term projections other forms of verification may arise, inter alia related to expected or attributed benefits as expressed by price adaptation in affected markets (e.g. land development). The reader is also referred to Deliverable D1.1 for a discussion on alternative categorisations of climate services.

5.2. Defining quality

Quality assurance is part of the quality management in an organisation. In the first place this requires a definition of quality. Nowadays the notion of quality is closely linked to the eventual usefulness of the product or service. According to Juran and Blanton Godfrey (1999) "*Quality means those features of products which meet customer needs and thereby provide customer satisfaction*". Harvey and Green (1993) identify quality in terms of *the extent to which a product or service meets the specifications of the customer*. The latter definition is more specific and – strictly taken – does not involve eventual results of use, making it easier to monitor than the first one. On the other hand the latter definition may lead to a restricted (defensive) type of QA, if learning by both users and providers is not addressed. For elusive products such as CS the users may have difficulties to formulate adequate specification, even if co-formulated with the CS providers, and they may even not directly (initially) know their needs in this respect.

Despite these differences both definitions imply that – eventually – the users of a product determine what are the relevant features of its quality, and at what level or status of these features the quality suffices. *Quality assurance* is to be organized through *quality planning* (incl. mechanisms to survey achievements), but needs to be supported by *quality control* (entailing the daily operational level of measuring and ensuring quality) and should eventually incite action through quality improvement. If during the quality planning phase certain dimensions of quality variability are not recognized, and therefore not monitored in the operational phases, even rigorous QA may nevertheless result in customer dissatisfaction or underutilization of the product or service.

A complication in case of *complex* products and services, as well as in case of *new* products and services, is the risk of inadequate articulation of needs by the user. Especially new (prospective) users may have difficulties to identify (all) needs or rather may be unable to relate (all) relevant needs with the capabilities of the product or service. On the other hand such a mismatch can be caused or aggravated by selective communication of subsets of the capabilities of products and services. A rapid pace of innovation can confound these problems. All in all we identify three main reasons for inadequate articulation (and consequent risk of mismatch):

- Imperfect knowledge of the user due to limited understanding or inherent uncertainty
- Imperfect knowledge due to lack of transparency within the user organization
- Imperfect knowledge due to unfit presentation of the capabilities of the product or service (incomplete and/or partly irrelevant features)

Foundations of quality goals can consist of one or more of the following:

- Technology (e.g. knowledge on durability and stress properties of components, processes and equipment)
- Market signals (typical quality gradations; WTP indicators; sustained sums in litigation)
- Benchmarks (e.g. in case of strategic improvement trajectories)
- (recent) past performance
- Project specific indicators

Technology may also refer to data processing protocols. The challenge is that quality measures, even though inspired by effects external to the climate service provider, are to be applied and monitored *mainly within* the own service generation process, while it can be extended to data providers (input side of the process). Furthermore, in the case of service provision, including provision of climate services, the generation and use of the service are closely intertwined or can even largely coincide (e.g. when advice and training are important ingredients).

Measurement of quality can be performed:

- Qualitatively (e.g. based on expert ratings or client feedback)
- Quantity (e.g. % exceeding a limit or % reject)
- Cost / effort (marginal internal or external cost of unit of quality improvement or relaxation)
- Framed in time …. as additional feature or to show development (e.g. pace of improvement)

While the ideal unit of measurement of quality ….

- Is understandable
- Provides an agreed basis for decision making
- Is conducive to uniform interpretation
- Is economical to apply
- Is compatible with existing designs of sensors, if other criteria also can be met

Finally it is good to realize that the cost of quality deficiency are in particular getting large when it leads to wrong decisions and actions. In principle the following three main types of cost can be identified with quality shortfall and subsequent corrective action:

- Cost of remediation / repair / correction (producer cost A1)
- Cost of demand loss through reputation loss (producer cost A2)
- Follow-up cost of deficient service in its use (consumer cost B)

In the case of climate services we assume that the prevailing situation is: B >> A1 + A2, and A2 > A1

5.3. Service quality and market failures

5.3.1. Failure types and consequences

Two main challenges can be identified regarding quality and quality assurance in climate service provision, which can also be commonly found among most other information based services, being:

- Uncertainty about appropriateness of considered services (*product fit uncertainty*)
- Uncertainty about the performance (related to the properties of the information products contained in the service, i.e. *product performance uncertainty*)

The traditional challenge is to manage the inherent (technical) quality of climate services, related to the performance uncertainty. This relates to the properties of the mediated data and other information, i.e. statistical properties, spatial and temporal scale, tractability of the origins and post-processing of provided data and other information. To a significant extent the QA for these aspects can be managed by means of internal processes, based on systematic monitoring and reporting, and consequent application and maintenance of meta-data per dataset, i.e. the quality management toolbox as outlined in the previous section. For other elements of climate services quality management would mean clear process management and communication, and adequate involvement of skilled personnel. Even if such uncertainties or limitations are well communicated to the client performance uncertainty remains, which may be aggravated if appropriateness uncertainty and performance uncertainty cannot be separated.

The other challenge, to optimize fitness of the climate service for particular types of users or uses, can only be managed by interacting with users. The two challenges are not entirely disjunct. The way the inherent quality is communicated to potential users may affect their evaluation of the service fitness. Furthermore, some technical properties, such as spatial and temporal resolution, may have prominent significance in the notion of fitness for potential users, e.g. if connectivity to other data and information is important. For elusive products such as climate services *product fit uncertainty* (Hong and Pavlou 2014) is important regarding the decision to use (particular types of) climate services. For its appreciation the recent literature on quality assessment of electronic services is helpful. Hong and Pavlou, while referring to Dimoka (2012) distinguish several sources for this uncertainty. On the one hand there may be inherent uncertainty propagated by the way the delivered information is post-processed, combined and applied to a decision context. Under such conditions learning by doing and experience of others can reduce the uncertainty. On the other hand the product fit uncertainty can be caused by uncertainty of the client regarding its objectives, priorities, and boundary conditions. In other words, once delivered the client may realize it needs (partly) something else. This latter type of uncertainty, rooted in capacity and skill limitations of the user, require close cooperation with the user, such as through co-design.

The way the above mentioned two challenges play out is also affected by the business model of the climate service provider. Fledderus et al (2015) explain that the quality uncertainty can be tackled by closed and open approaches. 'Closed' refers to a system of extensive (facts based) control of the organisation internal processes and results in a high input-quality guaranteed product. The further use and transformation of the provided information is however the responsibility of the client / user. This approach suits large scale (largely) automatized provision of information services, and when the information applications are very diverse and not interrelated, making it hard to design standardized protocols for extended quality assurance. In this case the aim is to assure the quality of the own information and service as good as possible, but to refrain from any quality assurance issue at the user side, apart from recommendation how to use the delivered information and indicate limitations in terms of uncertainty and representation of delivered data. From the preceding discussion it should be clear that this only suits skilled users, which can handle the uncertainties not covered by this approach.

The alternative is the open approach, which implies deep involvement of the user / client in the service generation process through recurrent consultation or co-design. This approach reduces risks for product (quality) mismatch, but is obviously labour intensive and hence gets easily expensive. Yet, in some cases it may be the only way to ensure delivery and use of meaningful and applicable climate services, which generate value added rather than misunderstanding or maladaptation. The dilemma will often be that less skilled (prospective) users will tend to have a lower willingness or capacity to allocate sufficient resources for this intense interaction option, which hints at the need for (separate) awareness raising action and/or at needs for supportive or cooperative structures for such user groups.

In economics, when it comes to understanding market consequences of product uncertainties, the concepts of *information asymmetry* (between providers and users), and *transaction cost* are key. If the realization of a transaction, including search, selection, and acquisition, is not costless, it means that there is an upper limit in terms of affordable additional information acquisition prior to product acquisition and hence not all uncertainty can be eradicated. This also means that selection of acceptable quality uncertainty is closely related to an explicit or implicit notion of what is the *minimal justifiable ratio of expected benefits and costs* of climate services and what is the willingness to take risks that the minimum cost-benefit ratio is not achieved. In this respect it is important to realize that in this case the cost-benefit ratio is not necessarily a clearly defined figure, but can also be a notion of what seems reasonable.

Performance uncertainty has also consequences for market volume and competitive positions of suppliers. The classic case was explained by Akerlof (1978), referring to *information asymmetry,* implying that the seller knows more than the buyer. In such uncertainty conditions inferior products get the upper hand when users cannot properly distinguish quality differences during acquisition, and provided inferior products are cheaper to make, while end-user prices do not (fully) reflect quality differences. The set-up requires that purchases are not very frequent and/or learning is hard to realize, whereas also economies of scale and scope should be small or moderate (otherwise better quality could still win). A part of the climate services market would by and large fit these conditions, if 'price' is replaced by a more comprehensive notion as 'allocated resources' (by the user).

In the absence of information asymmetry, while retaining output quality uncertainty, learning ability (affecting product expectations) makes a big difference in market outcomes over time, as shown in Izquierdo et al 2005 and 2007. The articles show that the consequence of experienced quality variation in combination with **not sharing** experiences is that the users with disappointing experiences in a previous period reduce their willingness to pay (WTP) in accordance with reduced product quality expectations. Given a linear ordered price variation of supply alternatives the market starts to shrink over time, while average quality drops as well. In the simulations the contraction could go up to 50%. The market would shrink even more in case of constant supply prices, and perhaps experience a smaller drop in quality (as may happen in bureaucratic settings). On the other hand, if all users can share their experiences efficiently, the discounting effect of product quality uncertainty diminishes.

5.3.2. Remedies

The various shortfalls with respect to quality assurance have somehow all to do with the access, comprehensibility, trustworthiness and accuracy of information. From the professional and academic literature can be inferred a collection of measures that can help to improve these features. Yet, these measures denote no panaceas, and may come along with other disadvantages, such as extra costs.

Altogether the following measures could help to alleviate the expected shortfalls. Each of them is briefly discussed. Subsequently, from the interviews, literature and survey can be inferred to what extent these options have been taken up.

- **Awareness raising (by user group)**
  Awareness raising can be an important preparatory measure in order to make target groups more receptive for activation oriented measures and information. For various potential CS user segments awareness raising seems highly necessary. Yet, if it remains quite detached – in terms of e.g. timing, framing and atmosphere from the follow-up measures, the effectiveness could be very limited (Roeder et al 2016). The once high hopes concerning effectiveness of awareness raising were based on the theory of reasoned action (Fishbein and Ajzen 1975) and on its evolved version, the theory of planned behavior (Ajzen 1985). These theories have proven validity, but tests show large uncertainties remain whether raised awareness leads to action (Madden et al 1992). Indeed, the latter theory identifies a significant role for 'perceived behavioural control'. Even though in the case of climate services we consider organizational behaviour as much as personal (decision makers') behaviour, this notion of control limitations seems to associate well with several suspected features such as lack of market transparency and product fit uncertainty. Furthermore, Drazkiewicz et al (2015) warn that higher awareness may also lead to reasoned non-engagement, if envisaged actions do not seem to contribute to ultimate objectives or otherwise can (also) lead to undesired side-effects. In case of wide spread shortfalls in awareness a long term view is needed. Awareness campaigns should as good as possible link to features that matter and appeal to the target group.

- **Certification and standardization**
  Certification can raise trust and reduce transaction cost, and hence may have considerable effect on raising the use of CS in a somewhat longer time perspective (i.e. 5 – 10 years). Yet, reliable certification is costly and takes time to develop and implement (Jahn et al 2004; Brounen and Kok 2011). Furthermore, there can be important trade-offs between general applicability (allowing wide spread standardization) and informational effectiveness (incl. accuracy) (Jahn et al 2004). Certification may also create notions of exclusiveness and have thereby club effects, which may cause split development pathways for different user groups.

  Standardization is related to certification and usually a prerequisite to it. Standardization in data handling protocols can promote the uptake of quality control and quality assurance procedures. Standardization can also be applied at the output side with respect to information presentation, which can make use and cooperation across (end)users easier.

- **Profiling users in terms of (initial) capacities**
  User profiling can help to improve matching probabilities of offers and demands. Several recent CS market assessment studies point at this issue (Vaughan et al 2016; Reinecke 2015). This means that this practice can (1) raise the probability that the most fitting product is selected, and (2) raise

overall take up as the probability of bad matches seems to decrease to some extent.

The C3S project SECTEUR is producing a repository of user needs database on extensive survey information of different types of users from different sectors (presentation by M. Bruno Soares in EU-MACS seminar 19.06.2017). That database could form a good building block for effective user profiling in connection with (envisaged) climate service product and delivery characteristics.

- **Mechanisms to promote learning** within and across user and provider organisations
  Even more than by awareness raising learning is realized by experiencing use and its reflection. Actors can learn from own experience as well as from experiences of others (see also section 6.3.1). Furthermore, the learning of the users is to be relayed to the CS providers so as to better orient further product development.

  Learning is facilitated by standardization in QA of data and information / service provision. *Learning from own experience* requires reflective mechanisms on the part of the user. *Social learning* can be promoted by establishing information and experience sharing facilities such as 'communities of users', which may entail information sharing via websites, but also by means of dedicated meetings, and coordinated feedback to CS providers. With uncertainties both at the user and the supplier side also co-design can be an effective mechanism, not only to produce the right service at that occasion, but also to jointly and mutually learn.

An important prerequisite for the effectiveness of these remedies is that CS providers have developed adequate business models for their climate services. As indicated in the preceding section, business models which presuppose a 'closed approach' for the service production process so as to maximize production control, are hard to combine with co-design concepts. As a general guideline it is good to realize that different clusters of climate services often merit different business models.

At an even more generic level also market structure plays an important role in the uptake and effectiveness of these remedies. Especially the instruments certification, standardization and social learning are easier to implement and more effective in case open and shared data policies prevail. On the other hand the increasing diversity and the need or inclination not to disclose data may complicate the effective application of these instruments. To this end and also to support open data policies in an imperfect world for example *blockchain technology* may be a crucial innovation (Swan 2015; Maupin 2017). Blockchain technology enables guaranteed verification in complex and evolving supply chains, without insistence of public disclosure or sharing of information – yet, there may be a very long way ahead to actual implementation.

6 CURRENT PRACTICES IN QUALITY ASSURANCE

6.1 Introduction

This chapter handles the set of topics listed in the box below, which are taken from the table with 12 topics of section 6.1, while maintaining the same numbering as in the original table. The discussion is based on literature review, web site scanes, interviews with CS providers (see Annex 3) and a part of the Task 1.1 survey questions (see Annex 4)

1. Practices regarding the information generation process – explicitly or implicitly declared (which steps included (point iii of accuracy); references to formalized procedures (WMO; ISO, etc.)
2. Practices regarding reporting on statistical properties and effects on selections
3. Practices to evaluate or indicate the fitness for (a particular) use
4. Practices regarding flexibility in spatial and/or temporal resolution and indication of quality implications
5. Practices regarding embedded CS (user guidance, advice, education, etc.) – e.g. is embedding adaptive, is it significant, etc.
6. Practices regarding ex-post user satisfaction measurement

9. Resourcing implications for rigour and application of QA

From the literature (Ludolf and von Flotow 2014; Gregow et al 2016) and the interviews can be inferred that the **position in the value chain** has a large impact on QA behaviour of a climate service provider. Furthermore, this position also steers to a significant extent how the involved experts perceive the produced climate services[13], in terms of the degree of research and innovation content as well as the degree of and scope of tailoring, and by implication the maturity of the climate service product (in as far as they can identify with the notion 'product'). For these reasons prior to discussing the above listed topics in section 7.3 first the nature of different types of climate service provision and its consequences for the perception of product maturity is discussed in section 7.2.

6.2 Nature and scope of services in relation to QA

Of the four types of climate services distinguished by content (seasonal (intra-annual) projections, historical series, multi-decadal climate change projections, and consultancy & schooling) seasonal products are still relatively rare in Europe, and tend to be offered by large institutes (NMS's) only. Impact oriented climate monitoring, e.g. for regional authorities such as cities and water boards, is a newly arising service form, often based on extensions of existing combined observation and projection networks, entailing a combination of the aforementioned types of climate services.

From the survey conducted in Task1.1 (see D1.1) question no.3 investigates the position of the climate service provider in the value chain (see Annex 8 for explanation and examples). So-called *upstream* positions refer to the initial steps in the value chain related to generation of data through observation and modelling as well as to some post-processing of data directly following the data generation. Climate services based on this kind of information is mainly used by researchers and experts in sectors with advanced numerical skills, such as in optimisation of electric power production. On the other hand *downstream* positions refers to (several) additional reprocessing steps making the climate information easy to interpret or combining it with

[13] Indeed, in some cases this perception extends to climate services in general, implying that different experts (may) have different perceptions of what still constitutes a climate service, and what are understood - at best - as related or derived products.

other non-climate data or even translate it into impacts on variables of interest of the user. The survey results (fig. 6-1) indicate that NMS's tend to cover more positions throughout the value chain, but this is largely attributable to their strong - often obligatory - presence in the upstream part of the chain (Anderson et al 2015). Upstream activities can be fairly often associated with fundamental and strategic research, even though they do contain also operational (routine) activities, notably observations and basic validation and verification (Rogers & Tsirkunov 2013).

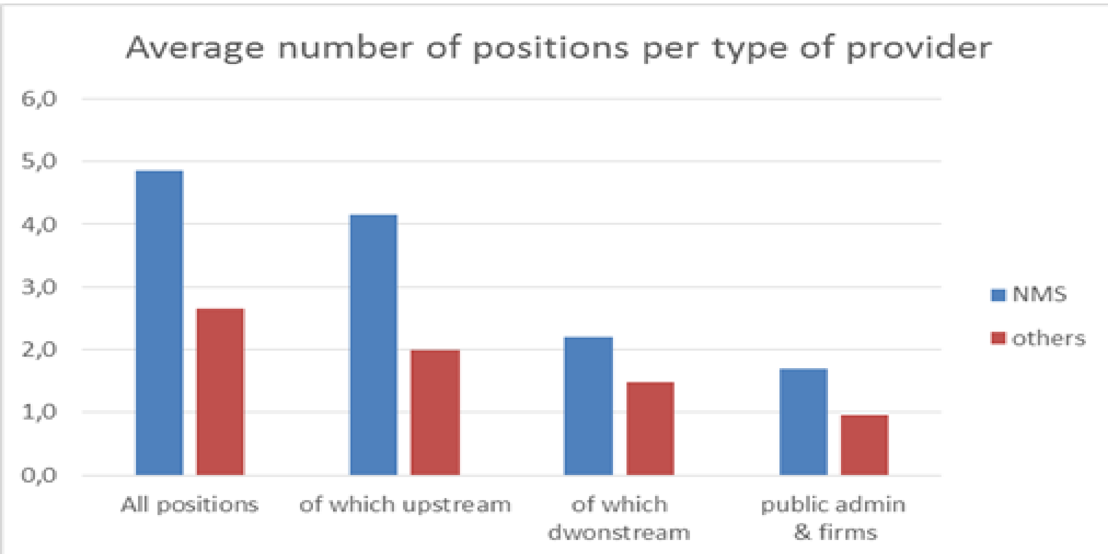

FIGURE 6-1 PREVALENCE OF NMS'S AND OTHER CS PROVIDERS IN DIFFERENT PARTS OF THE VALUE CHAIN

During the interviews all climate service providers indicated that there is a constant flow of innovation in the CS sector (questions 1-3, see Annex 4). Also climate service products that can be regarded as operational, usually still undergo upgrades, differentiations, etc. Some climate service providers, notably those with a strong research background (in a NMS) tend to see climate service provision still largely as a R&D activity, which includes demonstration to test and show the readiness of a particular climate service product. Another view is to distinguish upstream climate services clearly from downstream, where the former is strongly data driven and can be even more like a multi-purpose facility or infrastructure rather than a collection of service products. These perceptions greatly influence the views on what kind of quality assurance is required.

Anyhow all respondents (interview question no.3) underlined that the share of service products which is subject to significant innovation and research input was high, tentatively indicating ranges from 50% to 90%. It should however be realized that a high share of high level R&D in the own organisation tends to associate with *not* identifying limited (incremental) product improvements as innovation. In fact several respondents were of the opinion that a part of the activities 'labelled' as climate service has more the character of a development project or piloting project, rather than regular or even experimental service delivery.

Various interviewees wished to make a distinction regarding experience cumulated in a particular climate service product and experience embodied by the experts developing and/or delivering the climate services (question 2 of the interview). In most cases embodied expertise extends appreciably more years back than the cumulated experience of climate service products. NMS's can refer to already long time existing 'traditional' climate services based on historic observations. Yet, these services cover only a part of the portfolio, whereas the cumulated long term experience for those products has limited relevance regarding the ways of delivery of climate services. A part of the newer types of products is rooted in earlier versions dating back up to 10 years ago (with different levels of operational use). When ignoring small updates the current versions of climate services products mostly have ages ranging from a few years to a few months. This implies that respondents' answers are largely based on a reasonable amount of empirical knowledge.

Next to the association between position in the value chain and the share of innovation and in-house R&D activity (interview questions no.1 and 3), there is an association between position in the value chain and the inclination to embed climate service provision in advisory and consultancy activity and to reach out by including or even focusing on impact information expressed in decision variables of the user. Both the embedding and the outreach in terms of user relevant variables are less suited for application of the standard QA focused on the data sets containing only climate data.

The data generation pathway of climate datasets inevitably entails an accumulation of uncertainties. For historic time series the WMO has a series of guidelines (see Annex 5) how to proceed from adequate observation to reliable climatic datasets. These guidelines leave still some leeway on the exact choice of QA methods and in the extensiveness of communication about data origin and processing steps. If it comes to long term climate change projections, implying no verification options, uncertainty is managed by employing ensembles of forecasts, for which a host of literature exists on bias correction methods, and preferred ensemble size and selection. For the use of ensemble predictions the particular application purpose and location often results in quite specific requirements, making generalizations more difficult.

In the Copernicus Climate Change Services (C3S) are sub-programmes on quality assurance and related communication. The C3S projects, Evaluation and Quality Control for Observations (EQCO), Data Evaluation for Climate Models (DECM), , and Quality Assurance for Multi-model Seasonal Forecast Products (Q4SEAS) develop quality assessment concepts and applications for observation based climate data, long term climate projection data and seasonal climate projection data respectively. In turn this requires standardized data quality declarations (metadata) from data providers. Furthermore, as regards long term projections the project Climate Projections for the Copernicus Climate Data Store (CP4CDS) produce quality controlled datasets. More generally, the EUDAT data library facilities and the related national data repositories require meta-data declarations in standardized formats. Yet, at the moment there is still quite some leeway in how much of the metadata are actually declared.

Even though uncertainty is an aspect in the mechanisms reducing the uptake of climate services, it is not so much the alternative analytical approaches as such that have a lot of influence on the uptake, rather it is about **clarity in communication on data quality**, incl. statistical properties and origin, that matters. The transparency, comprehensiveness and comparability of the *communication* on uncertainty aspects of climate data as part of climate services is discussed in the next sections, as this appears to be an import building block of quality management of climate services.

6.3 Summary of the encountered practices regarding QA

The topics no.1-6 + no.9 are often addressed by more than one question from the survey and/or the interviews, while the review is further supported by literature. Table 6-1 below summarizes how questions and topics connect. It appeared that topic no.5, regarding the embedding of climate services in consultancy, education, and user support, is more like a logic consequence rather than an optional QA approach. Therefore this topic is handled throughout the discussion of the other topics. Furthermore, Annex 5 provides additional – more detailed – background information pertaining to topics no.1, 2 and 6.

TABLE 6-1 SUMMARY TABLE OF THE RELEVANCE OF SURVEY AND INTERVIEW QUESTIONS FOR INDENTIFIED TOPICS

	ANNEX 4	SURVEY						Interview								
		3. position in value chain	8. is there a QA process	9. contents of QA	10. provision of metadata	11. profiling fit for purpose	65, quality criterion significance for user	4. how define quality?	5. formalized QA system?	6. other quality properties than stat & data origin?	7. certification in use?	8. QA rating in CS offerings?	9. do you inquire users' quality perceptions?	10. define appropriateness of CS for user	11. QA extension options to users' data?	12 & 13 QA dependence on resources?
1. Practices regarding the information generation process; references to formalized procedures (WMO; ISO, etc.)	x	x	x						x		x					
2. Practices regarding reporting on statistical properties and effects on selections	x			x	x											
3. Practices to evaluate or indicate the fitness for (a particular) use						x	x	x		x		x	x	x		
4. Practices regarding flexibility in spatial and/or temporal resolution and indication of quality implications								x		x			x		x	
5. Practices regarding embedded CS (user guidance, advice, education, etc.) – e.g. is embedding adaptive, is it significant, etc.		x								x					x	
6. Practices regarding ex-post user satisfaction measurement	x						x						x	x		
9. Resourcing implications for rigour and application of QA		x														x

Prior to discussing practices it appears important to consider the user context and capabilities. From the literature (Cortekar 2016; Vaughan and Dessai 2012), the interviews (questions 4 & 10 to CS providers[14]), and the survey (questions 65-68 to users) can be inferred that user needs can differ vastly, also within one sector (e.g. urban planners) or topic (e.g. flood management). In this respect it seems – initially – important for the CS provider to get as soon as possible an impression of the *capabilities of an envisaged user*.

The practices regarding the user profiling differ across CS providers for several reasons. It depends on the chosen business model(s) and CS product portfolio, where the latter refers both to the distinction between seasonal products, long term projections, and historic series as well as to the degree of tailoring (mainly data, or also visualization, consultancy, and education). For seasonal products and even more so for long term projections (for adaptation purposes) repetitive consultation and co-design are rather the rule than the exception. Even though this view can be biased by the high share of pilot and development activities in these types of CS. The initial reflection on the kind of user should produce a user profile with implications for the understanding and communication of QA. Even if the business model is based on web-based information selection tools, the tool guidance and additional on-line guidance and feedback options try to match the user capabilities with the alternatives on offer. Yet, all in all no *systemized* theoretical underpinning nor applicable concept of user profiling was encountered in the interviews, which corroborates findings of Mañez et al (2014) on the same issue. From the interviews and the scarce literature arises the impression that the linkages between choices for particular business models and service portfolio choices and consequent user profiling practices tend to be not very thoroughly considered, even though various interviewees demonstrate awareness at this point. Furthermore, in consultancy oriented approaches this may

[14]. **Q4:** How would you define quality in case of climate services? – is the quality notion differentiated for different climate services? **Q10**: Would you expect that **appropriateness** of the climate service (in terms of contents and format) from the point of view of the user, notably regarding the compatibility with the user's other data, risk concepts, etc. is a key aspect of quality?

be less critical (see end of section 6.2) than in approaches based on particular (types of and/or delivery modes of) information products.

Topic 1 - QA practices in information generation

As regards topic no.1 survey questions no. 8 and 9[15] and interview questions 5 and 7[16] produced information. The survey results indicate that ⅔ of the NMSs and approximately half of the other types of climate service providers state to have at least some kind of formalized quality assurance system for (a part of) the building blocks of climate services (figure 6-2 - blue bars). It should be kept in mind that respondents may have interpreted the question with different degrees of strictness, as for seasonal and long term projections quality assurance procedures are still largely under development (e.g. in the COPERNICUS C2S programme; see also section 6.2 and Annex 5). When asked for specific elements of quality assurance (other bars in figure 6-2) NMSs distinguish clearly from the other climate service providers with distinctly higher shares for all elements. This may be partly owing to the obligatory WMO guidelines for NMSs, but also the type of climate service provided affects the response. The more inclusive and interactive the mode of service delivery is, the less prevalent formalized QA becomes, whereas other QA elements than data quality can become equally important e.g. regarding visualisation, compatibility with users' non-climate data, and user support.

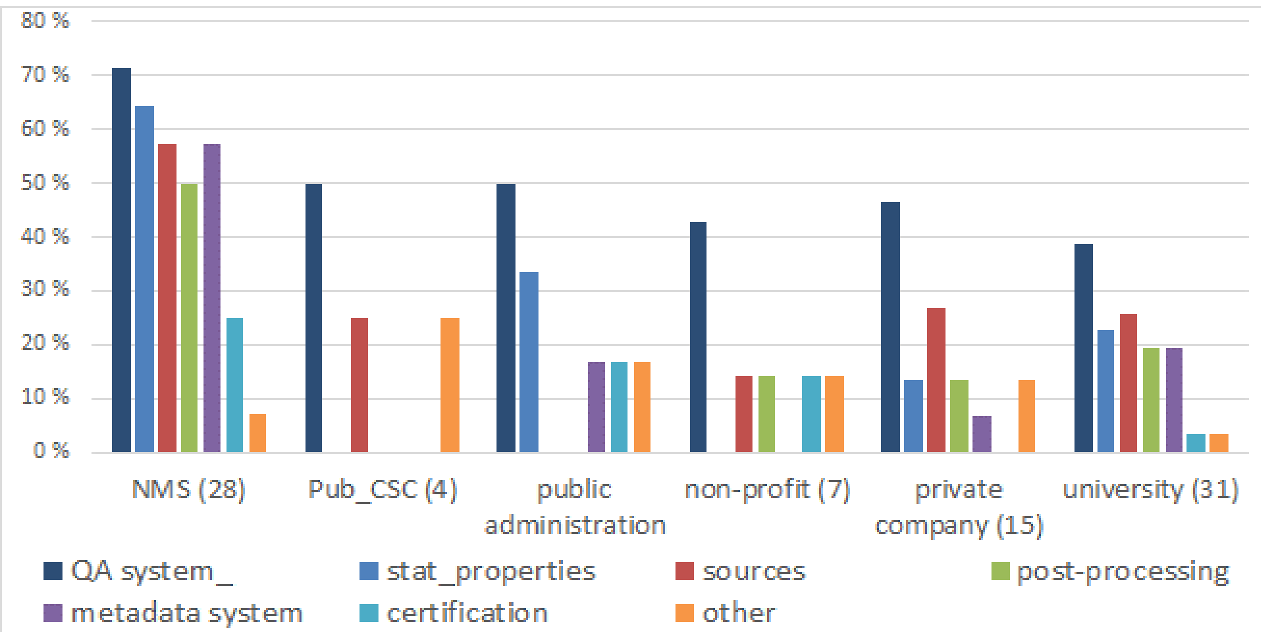

FIGURE 6-2 PREVALENCE OF QUALITY ASSURANCE IN GENERAL AND PARTICULAR QA ASPECTS FOR DIFFERENT CS PROVIDERS

In the interviews the reference to formalized QA systems (question 5) was answered by referring often to scientific methods and principles, WMO guidelines, and ISO90001 standards for observation data. Occasionally was mentioned the Earth System Grid Federation (ESGF) quality check procedures, Official

[15]. **Survey Q8:** Does your organisation operate a quality assurance process in relation to the supplied climate information? **Survey Q9:** Does this system include: Statistical properties of datasets / Declaration of the sources of the datasets (observations, simulations) / Declaration of post-processing steps (bias corrections, interpolation, etc.) / A systematic production and maintenance of metadata per dataset / Some kind of certification / Other

[16]. **Q5:** Do you have in your organisation a formalized system for checking and reporting statistical and database properties of datasets used for climate services? **Q7:** Does your organisation use quality certification protocols (e.g. ISO) for building blocks of climate services?

national (quality assured) statistics, and validated Value at Risk data. In addition most organisations have developed some specific validation methods, e.g. in relation to error propagation in models and modelling chains.

Apart from ISO90001 being relevant for QA in initial stages of data generation (observations) certification is as yet not regarded as an important issue. In relation to interview question 7 some interviewees also referred to codes of good conduct in the expert organisation.

Topic 2 - Practices regarding reporting of statistical properties and effects of selections

As answered for Topic 1 the interviewed CS providers refer to scientific methods and principles, WMO guidelines, ISO90001 and ESGF guidelines, and own internal guidelines (interview question 5). For *internal use* declarations on statistical properties, origin of data, and preceding processing steps are in most cases available, whereas this information may get more condensed when moving down the value chain. It remains unclear to what extent such declarations are standardized, easy to access, and maintained. One respondent pointed at a root problem, being the diversity in data sources entailing differences in meta-information reporting and differences in the conduct and description of post-processing steps.

Survey question 10 specifically asks about the provision of meta-data to users (figure 6-3). For NMSs it is clearly more customary to provide such information, albeit quite often only on request. For other providers this is less common, which can be partly explained by differences in the service portfolio, and partly by an often 'larger distance' to the original sources.

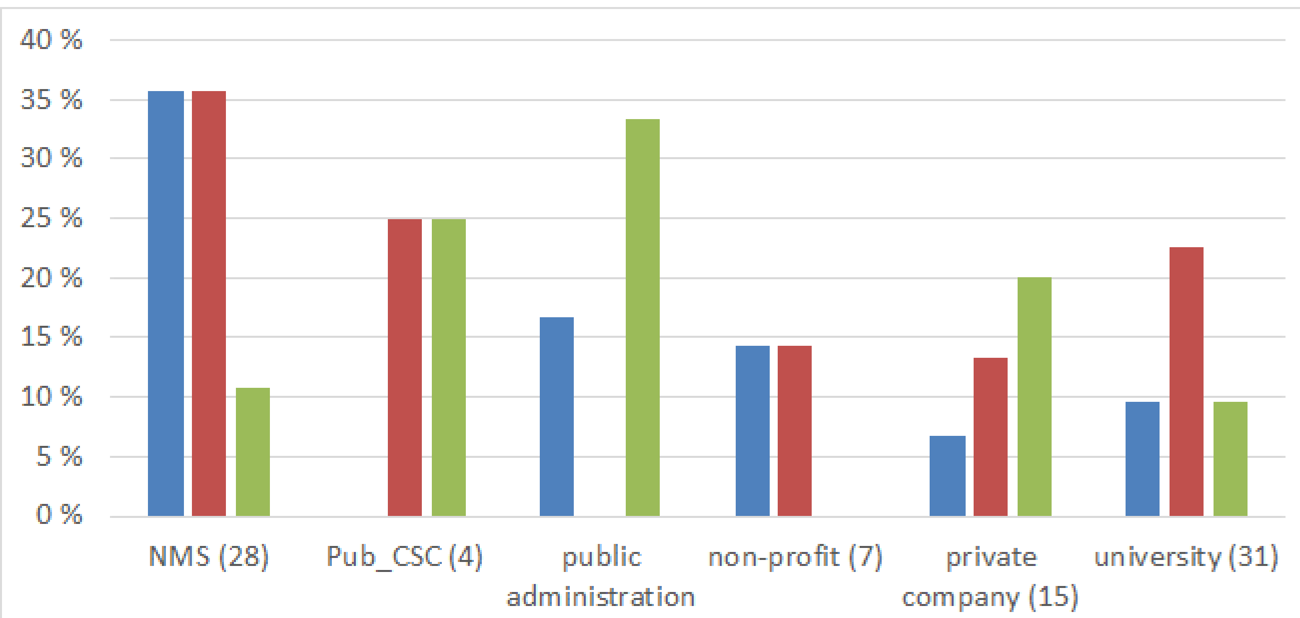

FIGURE 6-3 SHARES OF CS PROVIDERS OFFERING META-INFORMATION TO USERS

Topic 3 - practices to evaluate fitness for (particular) use

Some interviewees answered question 6[17] by referring to the need to inform users well about the limitations in the applications of the delivered information. A second category of answers refers to the significance of co-design and consultation procedures as a means to deal with QA elements that are harder to quantify and/or which are strongly context dependent. For consultancy oriented climate services QA has to

[17]. **Q6**: Apart from the statistical and database properties, what other aspects do you regard as important with respect to quality assurance of climate services? – do you (systematically) observe these other aspects?

encompass or even emphasize the information transfer and education process in addition to the delivered data. Last but not least several interviewees point at the use of user satisfaction evaluation (at the end of each assignment or annually for all clients).

With reference to interview question 8 it appears that most CS providers inform users about uncertainty ranges of provided data, some as standard practice others upon request, and in some cases this practice is in particular guided by the needs and capabilities of the user. Unless the users are highly professional climate data users themselves, information about origin and processing steps is usually not provided, as various interviews testify that users do not show interest in this information. Either in conjunction with the uncertainty information or as separate action all CS providers do inform users about limitations in application of the provided data or information. In case of co-design processes the explanation on limitations is embedded in the consultative process.

As regards inquiry about quality perceptions of the user (question 9[18]) most interviewees refer to co-design and consultation processes, from which sort of automatically emerges (some degree of) understanding of the quality notions of the user. In case of web-based and largely web guided CS provision it is attempted to inform users about quality implications of choices, and sometimes also to elicit the intended type of application. If the climate service entails expression of climate impacts in variables which are familiar to the decision system of the user, feedback regarding the user's quality notions become much more pertinent. One interviewee mentioned the role of such feedback as part of further product development and refinement. On the other hand long term cooperation experience with actors from the same sector usually results in better understanding of the user's quality notions, especially if these are steered by government regulation (such as regarding climate change adaptation obligations in land use planning).

In the survey (Q10[19]) a clear majority of the NMSs and universities states that fit for purpose of the user is evaluated, even though especially in NMSs it is not yet very common to do that together with the (envisaged) user (figure 6-4). It should be realised that a part of the respondents may have understood fitness for purpose in the technical data quality sense, rather than a broader scoped user perception based notion of fitness for use.

In the survey respondents being purely CS users were separately asked (Q65) to rate the significance of different quality attributes (figure 6-5). A large majority of these users, mostly situated more downward in the value chain, rate combinability of data with own information and relevance for the own decision process as very important or at least as important. This hints at the significance of quality concepts beyond statistical properties of climate data, better linking to the use needs and practices of the user. Costs seem to be less critical. Yet it possible that the sample suffers from selectivity bias. Perceived high cost may be a reason for not using CS (see also Topic no.9 and Deliverable 1.1).

It should be emphasized that even in case of more intensive consultation or co-design the CS provider may not know (precisely) how the provided information is used in the subsequent stages of the value chain, e.g. how the provided data are combined with other data used by the user. It remained unclear to what extent this lack of insight in subsequent use deteriorates the effectiveness of QA measures.

[18] **Q9:** Does interaction with potential users and service delivery to users include inquiries about quality perceptions of the user?
[19] **Survey Q10**: Do you offer advice and/or tools to users to evaluate the fitness for purpose of climate information?

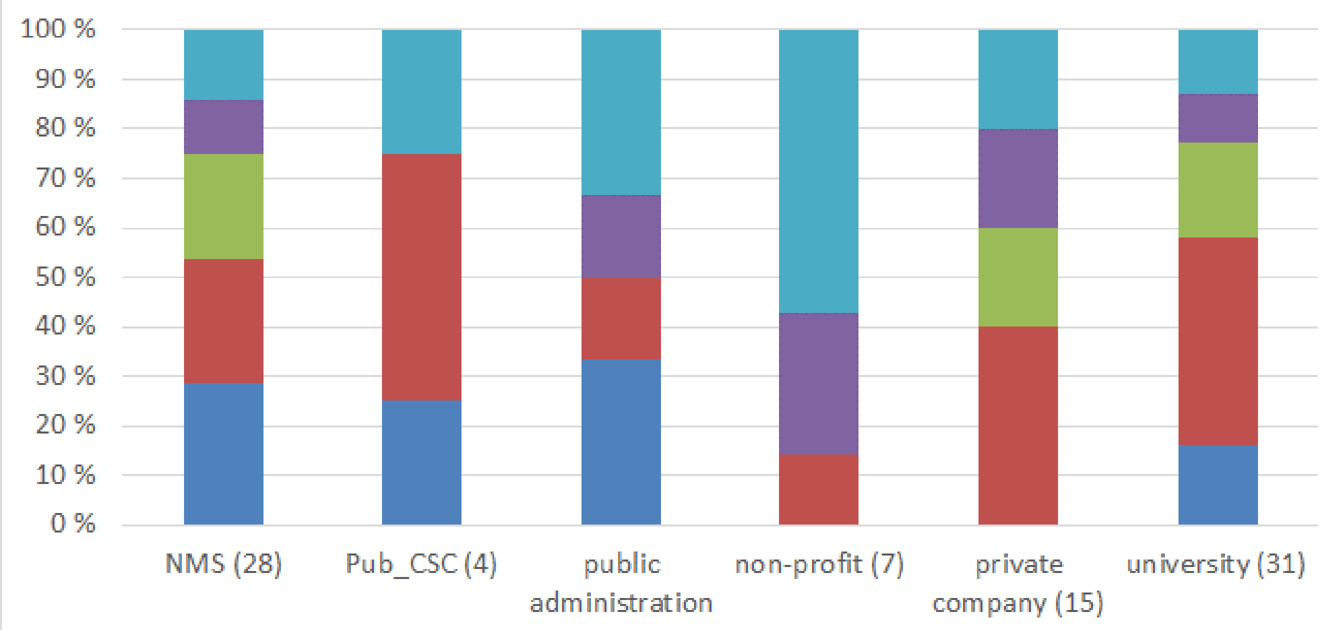

FIGURE 6-4 CS PROVIDER'S PRACTICES REGARDING EVALUATING FITNESS FOR PURPOSE OF USERS

In the COPERNICUS C2S programme the term 'fit for purpose' is used with reference to statistical properties and data origins of resulting time series and datasets with an eye to allowable uses of such data, notably in terms of spatial and temporal resolution and in terms of the representative character of averages and other moments of the distributions. In the light of the preceding discussions it may be clear that this term ('fit for purpose') has only a rather generic indicative significance.

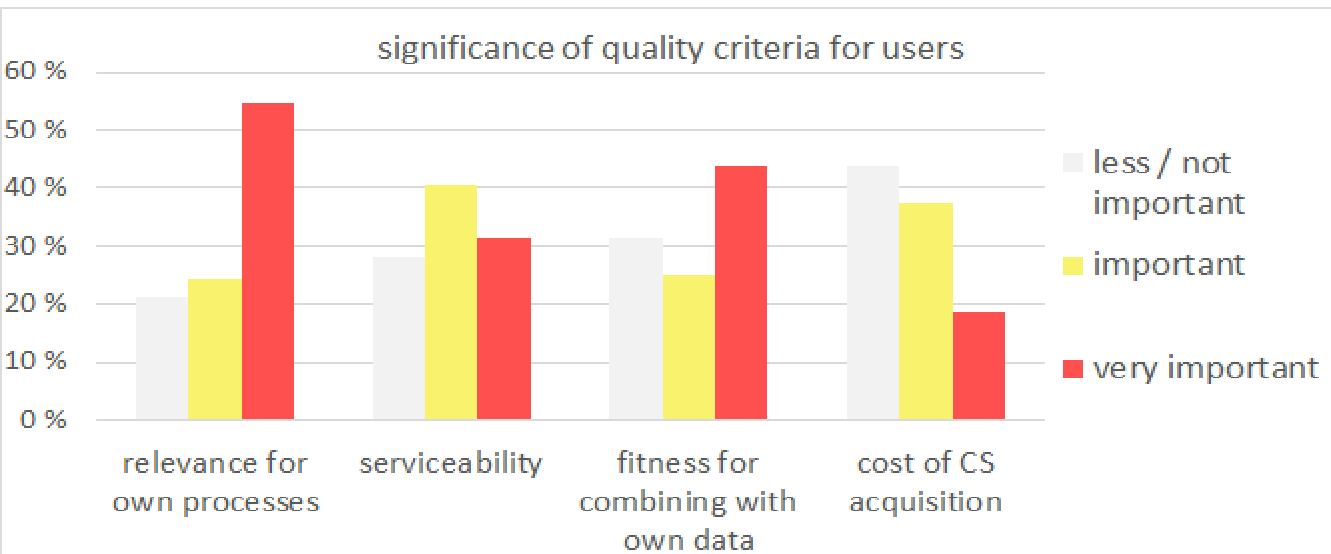

FIGURE 6-5 USER RATINGS OF THE SIGNIFICANCE OF QUALITY ATTRIBUTES OF CLIMATE SERVICES

Topic 4 - Practices regarding flexibility in spatial and/or temporal resolution and indication of quality implications

As indicated above in relation interview questions 4, 6 and 9 CS providers will usually inform users about limitations in the use of the delivered data. Especially in case of co-design or intensive consultation based CS provision some degree of flexibility is built in, while at the same time informing users about implications of the uncertainty ranges in the data. Yet, various interviewees admonished they have no or limited knowledge of how users are actually treating the climate information after service delivery or consultancy is completed. Various providers have developed more or less standardized lay-outs for presentation of key results, with a varying degree of differentiation of such presentation templates by user type or sector. Further development of those products depends strongly on user interaction and user feedback.

From survey question 65 (figure 6-5) can be inferred that good combinability with other data of the user (e.g. thanks to same or comparable spatial resolution) is highly appreciated. In Annex 6 is illustrated that such checks would be possible and help to differentiate warnings on limitations, such that appropriate rescaling can be applied, while staying alert for localized loss of quality. With respect to interview question 11 interviewees indicated that this need is accommodated to some extent, either because the output is expressed in the (appropriately scaled) variables of interest for the user or because this absorbed – to the extent possible – in the co-design process. In most cases it is however not common practice, and neither are there standardized approaches available for this need.

Topic 6 – Practices regarding ex-post user satisfaction measurement

In conjunction with interview questions 6 and 10 interviewees indicated several practices regarding measurement of user satisfaction. Some CS providers, notably those delivering more than just data, will ask users at the end of the service delivery process to evaluate (rate) the service delivery, both in terms of delivered information and in terms of the process. Forms may be used to support the evaluation. Data transfer oriented CS providers tend to use automated feedback options, including options to rate satisfaction with the data and the delivery process. Alongside and/or instead of these specific feedback channels some CS providers run a separate more generic client satisfaction survey, which can entail information on climate services delivery. Last but not least ex-post evaluation workshops were mentioned, either with large users after several rounds of use or with several users from the same sector (sectors where competition has no or limited relevance, such as urban planning).

Topic 9 - Implications of resourcing for the rigour and application of QA

The interviewees stated that for CS providers (interview question 12[20]), notably those in the upstream part of the value chain, resources are usually not the limiting factor for an adequate level of QA. Either a priori public funds have been allocated to enable adequate quality or – in case of charged services – the service will be cast as a premium product (justifying a price which enables cost coverage). In the margin and for some new products establishing appropriate QA may face some resourcing limitations as precipitated development of QA can be very costly. When answering these questions interviewees tended to have principally the traditional notion of QA in mind, while for some also presentation quality (such as visualisation) was – to some extent - considered. The willingness to spend large amounts of resources on other elements than data quality was not explicitly tested. Nevertheless, previous answers hint a default situation in which it is not self-evident to boost resource use for those, without suggesting that these are neglected.

[20] **Q12:** Is quality assurance dependent on resourcing and business models at the side of climate service provider or purveyor?

Various interviewees felt that they did not have well founded knowledge on the relevance of resourcing for QA at the user side. On the other hand several testified that (limits in) resourcing bears more relevance regarding (smaller) user organisations with limited capabilities for exploiting CS truly adequately. In this respect the results from the survey questions 66 and 67 provide some help. Most respondents (88%) indicate that CS acquisition costs were modest or negligible (Q66). On the other hand the use of CS after acquisition seems to cause often (50% of respondents) additional resource use for the user in terms of human resources and/or equipment and software (Q67). Even though the extra resource allocation may well have a wider basis it seems likely that for many organisations a *meaningful use* of CS services is not a trivial decision for the organisation regarding resourcing and information management processes.

6.4 Lessons from energy services

Elevated attention for energy efficiency and energy saving was ignited by the so-called oil crises in the seventies and early eighties of the previous century (Schipper and Meyers 1992; Mallaburn and Eyre 2014). Western countries typically responded by reducing oil dependency and energy import dependency. This notion of economic resilience is still acknowledged in energy efficiency policies (Lechtenböhmer et al 2006; Mallaburn and Eyre 2014). Climate change mitigation policies added new drivers to the initial economic resilience motivation. Also energy poverty and (local) employment creation are mentioned as motivations for emphasizing energy efficiency policies, at least in some countries (Mallaburn and Eyre 2014).

In connection with the promotion of energy efficiency, energy saving and of integration of renewable energy use in the built environment the EU adopted the Energy Services Directive in 2006 (2006/32/EC), which was replaced by the Energy Efficiency Directive in 2012 (2012/27/EU), in which energy services still have a central role. For quite some time the notion of 'energy services' caused confusion (Fell 2017), which to some extent still continues to exist (Fell 2017; Kindström et al 2017). From the review by Fell can also be inferred that the confusion associates with the broadness of the scope of the value chain the actor wishes to consider as relevant, i.e. does it comprise the delivery of (centrally) converted energy to (end)users or also the various application of the delivered energy at the (end)user's location (lighting, process heat, etc.) or even the contribution to the valorisation of the resulting output of the (end)user ('ready meal', 'thermal comfort'). These discussions are very similar as the ones identified in this Deliverable as well as D1.1 with respect to how a far down the value chain a climate service should be cast. A key concept in both policy areas is the business model around the service(s), and the extent to which it is consciously conceived. Energy supply companies with a strong traditional 'energy utility legacy' may face more problems in adopting effective energy services concepts (Kindström et al 2017). This is somewhat comparable to the position of NMS's in the climate services field (or market).

Nevertheless, despite various interpretations of the term 'energy services', the definition applied by the 2006 and 2012 Directives have provided guidance, while indeed various actors may apply their own tailored definition – fit for the envisaged business model. Over time a large variety of actors is contributing to an energy services market – or rather markets, as the greater part of these activities is at Member State level owing to variations in regulation, differences in market details and cultural and language differences. A substantial part of the market is policy dependent, without institutional frameworks, norms, fiscal measures, subsidies, reporting and monitoring obligations, etc. etc. a much smaller energy services market would have evolved (Sorell 2015). Furthermore, the current size of the energy services market is still regarded as insufficient from the point of view of European and Global emission reduction ambitions (Kindström et al 2017).

Kindström et al (2017) studied the Swedish market for energy services in as far as provided by energy supply companies (electricity and district heat companies). The logic to select this group is the favourable point of departure for these companies as compared to independent newly established energy service companies in terms of ownership of relevant data for service development and customer profiling. This is broadly speaking comparable to the positions of many NMSs with respect to starting climate services. Even though the energy services concept is much longer around than that of climate services, energy services provision does not seem to be deployed easily by energy supply companies in Sweden (or elsewhere for that matter). To develop energy services that appeal customers energy companies need to allocate sufficient resources and adequate expertise (in-house or third party). Kindström et al illustrate that this is often not the case. Furthermore, from the surveyed and interviewed companies it remained unclear how significant the energy services activities were within the overall activity portfolio and turnover of the considered companies. Other obstacles to uptake are the limited understanding of energy efficiency potential and options among customers and lack of strategic emphasis and guidance regarding energy services development in energy companies. On the other hand financial resource availability was – in principle – not a major barrier among energy companies. This latter theme differs somewhat from the climate services providers, where financial limitations play some role. Yet, overall the similarities are quite striking and in this respect it is important to realize that energy efficiency policy, energy services and the related institutional frameworks are already truly longer in existence than (modern) climate services. Key messages for climate services market development are: adequate institutional framework and supportive policies, reduction of the various elements of the transaction cost (searching, selecting, product uncertainty), and awareness raising – notably in hitherto less knowledgeable user sectors.

6.5 Summary of messages

Based on the discussion in the discussion in the preceding sections and chapters, the following key observations can be made:

- Defining the (targeted types of) user/client should precede definition of quality and its assurance
- QA methods and contents (should) correspond with the position(s) in the value chain
- QA methods (should) get more flexible the more the service delivery extends into user's domain
- QA methods (should) contain communicative aspects notably in downstream CS
- in upstream CS - data quality and origin declarations are becoming already quite accepted QA measures - COPERNICUS C3S sets the (high) standards for this
- Despite accepted general QA principles there is (as yet) limited transparency and unity regarding implemented indicators and underlying protocols
- Uncertainty properties may interest users, data origin much less so, unless users are strongly R&D oriented
- So far there is a limited role for certification; for more upstream situated CS users are inclined to use the scientifically grounded meta-data, whereas downstream CS products have a higher degree of flexibility and often a significant process element, making meaningful certification hard to apply as long as there is little standardization in approaches
- The significance of resourcing for QA depends on the type of CS provider (and user)

Subsequently, for a selection of problems we summarize prevailing current practice and upcoming or desirable new practices with respect to QA. Once again, a part of the observations illustrates that improving QA is not just a technical matter, but will often start with understanding the market position and the (prospective) users of CS.

TABLE 6-2 SUMMARY OVERVIEW OF CURRENT AND UPCOMING/DESIRABLE QA PRACTICES

QA problem or challenge	**Existing practices**	**New / Alternative practices**
Data quality focus vs. user perception based	Meta-data on data properties, data origin and post-processing steps; Possibly statements on meaningful lower boundaries of spatial or temporal resolution	Differentiate quality information by product segment and user group; for upstream/midstream existing practice may suffice; For midstream/downstream quality statements should be tied to application suitability; Aim for standardized formats (e.g. conformC3S)
Value chain segment dependence of QA	Especially among many public and academic CS providers QA tends to be automatically identified with data quality only, which is understandable (but still somewhat narrow) for upstream CS, but more seriously contributes to product fit uncertainty for downstream users	Identify and differentiate QA needs to the extent of being upstream, midstream or downstream in the value chain of CS. In practice this means for example differences in mode of provision, extent of supplementary advice, consultancy options, appropriate language, etc.
QA differentiation by CS delivery type	This relates partly to the previous problem, but links also to standardization in QA practices, incl. their presentation (communication). So far the completeness, availability and ease of use vary considerably, but there attempts to improve situation	C3S Climate Data Store QA will bring in good standards for upstream CS, and will give clues for downstream QA harmonisation initiatives, e.g. with data comparison tools. For downstream QA more development and piloting on common practices and standards would be highly welcome.
QA may/should extend into CS use process at user side	Spatial and temporal resolutions of climate data are specified	Tools to assess or at least explore trade-offs implied by resolution choices would be helpful. Sharing past experiences with different choices on combining climate and non-climate data enables systematic evaluation and better founded advice.
QA maintenance	QA information tends to be static (once formed databases)	Data comparison tools in conjunction with innovations in climate data observation & generation as well as in non-climate data generation (incl. visualisation) may greatly affect QA, also of existing datasets for which the use-options and relative fitness may change.

7 LEGAL DRIVERS AND ETHICAL NOTIONS

Besides the more technical and delivery model related topics discussed above also the following more social and legal context related topics were considered in the literature review and interviews.

7.	Legal imperatives regarding the above practices (obligations; accountability; …)
8.	Ethical guidelines on good conduct in supply and use of CS? (none; implicit; explicit)

By means of a literature review, we investigated how legislation promotes the usage of climate projections to support national adaptation efforts. The focus was on how (or if) legislative frameworks stipulate the usage of 'best' available climate information in spatial planning The review looked at two countries that are seen as having pioneering roles in adaptation activities: Germany and the United Kingdom (UK). (see Annex 7), while briefly also some impressions from Finland are added.

Key messages from recent studies (Hackenbruch et al. 2017, Bubeck et al., 2016, Lorenz et al., 2016, Porter et al., 2015):

- In Germany and the UK, the use of climate projections has not been successfully integrated into local strategic and adaptation planning;
- Most German municipalities take and use climate information offered by higher authorities at the state or federal level and rarely consider information offered by scientific institutions or other expert providers;
- The strongly regulated German Federal Regional Planning Act (Raumordnungsgesetz, ROG) favours the use of (observation) data based on past and present conditions, instead of climate projections, because it requires the use of concrete and accurate information and hence prevents the use of climate projections due to their inherent uncertainty;
- Not using climate projections is not so much an issue of insufficient technical capacity or lack of tools, but rather a matter of poor fit with regulatory and institutional requirements in the German planning system;
- In the UK, municipalities seem to be aware of the 'best' available climate information, but they only use this information in the early process of planning for awareness raising rather than integrating it into the wider planning processes;
- The UK case showed that a top-down push by the central government advocating the use of national climate projections (UK Climate Projections 2009 (UKCP09)) resulted in an early uptake of these by municipalities. This action has greatly helped to largely overcome the barriers regarding informational access and cognitive understanding.

A number of nationally funded projects aim to promote the usage of climate projections in adaptation planning. A national coordinated effort (ReKliEs-De, http://reklies.hlnug.de) analyses and complements a new set of climate projections for Germany. The goal of ReKliEs-De is to derive robust climate change information on high spatial resolution (12.5 km x 12.5 km ReKliEs-De-grid) for Germany. The pilot project of spatial planning "KlimaMORO" (http://klimamoro.de) that developed adaptation strategies to climate change between 2009 and 2014 for pilot regions in Germany has an expert group working on 'data and standards' testing how the usage of climate projections can be promoted in spatial planning.

Addressing the question of usability is not just about better understanding the interplay between what science or climate services can provide and what municipalities need or want, but also about what users can actually do within the political and economic constraints. Beside these constraints also cultural and civic factors need to be considered. The comparative analysis by Skelton et al., 2017 revealed that national climate scenarios are strongly influenced by the civic epistemology of each country, which defines who has a say, what roles scientists and users should play and how the two interact. The author team concludes that several future discussions are needed to better understand the different cultures for producing climate information.

Yet, as regards quality assurance there are no explicit regulations on minimum quality standards. To the extent possible, adaptation law and policy should be based on the best available science and climate information. However, law is not known for its swift response to new information and legal reforms often lag well-behind rapidly remerging science (Bubeck et al., 2016; McDonald, 2011)

For Finland could be added that the Ministry of Environment, which also oversees land-use planning, and building codes in Finland, has stipulated (Ministry of the Environment 2016) that municipalities have to account for climate change in their land-use and development plans, as well as consider possible climate risks (e.g. localized flood risks) when granting building permits. The Finnish Association of Local Authorities (Kuntaliitto) publishes among others an authoritative handbook with storm water guidelines (Hulevesiopas 2017 update), which accounts for climate change effects in conjunction with other legislation such as the national implementation of the EU Water Directive. Yet, formally municipalities and other relevant public bodies have the discretion in what way they take climate change effects into account and what sources they use for that procedure. In practice it seems to result – for the time being – in a situation in which larger cities and public authorities holding large amounts of physical infrastructure tend to have implemented binding guidelines with respect to new constructions and new area development, whereas smaller municipalities and other authorities may lack clear – let alone binding – guidelines. Hence larger cities and significant infrastructure organisations have been and are using climate services in the planning phase (for adaptation purposes) and to some extent also related to planning for snow clearing preparedness (entailing (sub)-seasonal climate services). Nordic electricity companies also use (sub)-seasonal climate services.

A part of the adaptation related guidelines and measures were also steered by other concerns and national or European legislation. For example, the public disclosure of high resolution flood risk maps (e.g. relevant for real estate management) was in the first place driven by the EU Water Directive. The publication appeared to be effective in terms of a fairly accurate price adjustment of dwellings in affected cities (Votsis and Perrels, 2016), but the link to climate change effects is not so strong, as e.g. future expected flood risks levels are not indicated in those maps.

As regards the finance sector can be witnessed that an increasing number of central banks and other financial supervisory bodies in Europe are investigating whether climate change and climate policy necessitates regular reporting on risk disclosure regarding impacts of and impacts on investment caused climate change and climate policy (UK: Bank of England; Sweden: Riksbanken; The Netherlands: De Nederlandsche Bank; France: legislation on climate risk disclosure for institutional investors (art. 173-VI); International: Financial Stability Board – Task Force on Climate Related Financial Disclosures). These initiatives are just unfolding, whereas the need for international coordination is acknowledged to be large.

PART D

Synthesis

8 CONSEQUENCES OF CURRENT BUSINESS MODELS AND QA PRACTICES

We evaluate the findings from the previous chapters. For all three topics, business models, quality assurance, and regulatory conditions all insights produced by both Tasks are used, i.e. for each of the next three section all previous chapters count. In addition we discuss how the findings may relate to the innovation angle and the Constructive Technology Assessment approach as applied in EU-MACS (see also Deliverable D1.4).

8.1 Main messages – business models

Key points

- The greater part of *current* climate services (CS) related activities is realized under non-market conditions
- Resource use for CS research, development and piloting seems as yet much larger than for actual CS delivery
- Public funding of CS activities has been hitherto clearly more significant than private funding, but this can change significantly as more CS become operational and more user segments get activated
- CS are a class of sustainable innovations – building blocks for a sustainable transition of society, …
- … therefore many users cast CS as a flexible cluster of monitoring, information, analysis, decision support, advice, training and brokerage activities which serve adaptation, mitigation and/or coping with climate variability or even other environmental and socio-ecological issues
- (public-private) *partnerships* seem often a very suitable organisation type for CS delivery or for CS brokerage, enabling a broad and malleable collection of skills and data
- Various, mainly private sector, user segments adhere great value to timely and agile provision of climate services, and therefore prefer private climate service providers over others, also implying that partnerships may be used for brokerage but much less for actual CS delivery
- Consequent implementation of *open data policy* is important for the CS market to abound. Both for reasons of equitable balances between private and social benefits and for reasons of healthy data infrastructure continuity royalty systems could be considered, provided the principles and purposes of open data are not compromised
- In particular public CS providers and public-private partnerships for CS provision should pay sufficient attention to business model development and recurrent review, and in accordance with their position in the value chain; furthermore, also at the CS user side there may be options for sector or regional coordination or centralization of CS acquisition

When considering encountered business models, it should be realized that the as yet *quite immature* climate services market operates within a larger evolving climate services field, in which a substantial part of the activities are driven and motivated in non-market conditions. This means that many CS providers with a public sector background encounter twin challenges.

In the first place a public budgeting steered organisation may not be best placed to fully appreciate all four building blocks of a business model and their inter-relations. Furthermore, the managerial drivers and prerequisites to run a research or product development organisation are quite different from running operational climate services, even if there are significant commonalities in required skills and knowledge.

Secondly, the fairly fast pace of contents and process innovation in climate services and the constituent building blocks (observation, modelling, post-processing, visualisation, data access, co-design processes, etc.) engender dynamics in preferred business models, and hence *malleable* business models may have advantages. This challenge is probably also a motivation for the steady growth in cooperative structures in CS provision.

Even though some types of climate services have old roots, overall, climate services provision can be regarded as a *specific class of sustainable innovations*, having its own role in a sustainable and resilient transition of economy and society, and cutting across mitigation, adaptation, and resilience promotion efforts. From a climate services point of view the contributions to mitigation have to do with the adaption and climate variability factors in mitigation efforts, e.g. through accounting for weather and climate sensitivity in appraisal of renewable energy sources. Yet, for several user segments, such as the finance sector, this distinction has become blurred and consequently for users 'climate risks' and also 'climate services' can just as well comprise greenhouse gas intensity or reduction issues as it can concern risk reduction by adapting to climate change and/or by better coping with climate variability or even concern other sustainability issues somehow related to mitigation or adaptation efforts.

The activities comprised in the climate services field constitute for the greater part of research and development activities, either meant to develop prototype climate services, to pilot climate services or to do research on building blocks of climate services (observation technology, climate modelling, post-processing and correction techniques, visualisation, etc.). These activities are often organised as projects, predominantly funded from public national or international (EU) sources, and also to a large extent realized by public and semi-public research and expertise organisations. In as far as this is a market it is one typified by tendering research funds through grants won in competitive bids, within the confines of a prefixed programme budget. Even though public and semi-public CS providers can be found throughout the value chain, their presence is relatively strongest in the upstream part of the value chain, owing to higher data and modelling input intensity in such CS services. These public actors, notably NMSs, public climate centres and some academic institutes, have a natural advantage with respect to these inputs.

A significant share of these R&D activities is carried out in consortia, which helps to promote multi-disciplinary approaches and involvement of stakeholders, and can offer starting platforms for more lasting forms cooperation. Indeed cooperative public-private and public-public structures are emerging ever more in the climate services field, and also in its subset, the climate services market. Even though the output of these publicly funded R&D projects is usually of high quality and in more recent years often also includes demonstration of the practical applicability of the developed products, the actual conversion of these concept products into climate services is not always self-evident. On the one hand this has to do with too little or belated attention for appropriate business models as well as the inherent fixed term character of R&D projects, while on the other hand also the involvement of commercial test-users can entail inhibitions to sharing of insights and climate service designs. Timely and more thorough preparation of business model options in publicly funded CS development projects seems to be called for. Similarly, the inclusion of confidentiality clauses in publicly funded CS development projects with private test-users is justifiable from the point of view of convincing private companies to join CS development projects, but from the point of view of generating maximum societal benefit from the public R&D funding the confidentiality clauses should have a limited duration.

Private CS providers can be either dedicated expert organisations or departments (or flexibly composed expert teams) of companies providing also other somehow related services, such as economic, technical, and environmental consultancy, insurances, and risk classification. Indeed a growing number of actors from diverse consultancy backgrounds and finance/insurance is getting interested in extending their portfolio to 'climate services', thereby often using the broad scoped notion explained above. As private CS providers their activities almost completely belong to the CS *market* (as distinct from the rest of the CS *field*), supplemented with some participation in piloting and development projects. Private CS providers seem to have a large share in the CS delivery to private sector users, partly because of larger flexibility and agility as well as a broader scope of consultancy products and partly because private sector users tend to expect that private CS providers are better prepared for maintaining confidentiality than other CS providers. For a successful engagement of private CS provision it is important to fully implement and sustain open data policies, thereby offering a level playing field for different types of CS providers, be they public, private or mixed partnerships. Yet, if an open-data-enabled privately generated CS implies persistent confidentiality of products and insights, this may hamper uptake of CS among (smaller) private and perhaps public actors in that sector, either assuming a free riding role or picturing themselves as disadvantaged. In case of privately owned critical infrastructure such hampered deployment of CS may lower societal resilience, which justifies measures to incentivise the sharing of CS information (at least to some extent). Another interesting situation arises if CS users manage to create lasting and very substantial profits from CS wholly or largely based on open data free of charge, while not sharing information. In that case there could arise a case for the establishment of an open data royalty system (with data sharing incentivizing features). Royalty systems could also help to ensure durability of the public open data collection systems, since continuous quality control and assurance in a vast and growing earth data system is costly.

Co-production partnerships for CS provision seem to be particularly well suited for CS brokerage & advice, as such activity by its very nature requires extensive networking as well as excellent data-access. At the same time the unfolding of the CS market would be certainly helped by user needs based brokerage (incl. advice on search and selection). The inclusion of public and private actors under a common framework boosts innovation throughout effective collaboration and knowledge production. In particular, the use of open-source infrastructures increases the credibility and the standardisation of protocols and methods and reaches a growing number of potential stakeholders.

Results from the semi-structured interviews showed that large attention has been paid to a shared terminology, starting with climate change itself. In fact, private actors are including climate-related products and services in the broad concept of "sustainability". This implies that firms are delivering projections, insurance products, but also carbon-reduction activities and mitigation actions, carbon footprints and sustainability reports. This has to be taken into account as one of the major differences among stakeholders: a significant heterogeneity between actors generates an even more fragmented market for Climate Services.

The interviews, conducted in the context of Tasks 1.2 and 1.3 largely confirmed the picture arising from the survey reported in Deliverable 1.1. From the side of public funded – development and piloting oriented – projects, practically all interviewees mentioned substantial lack of user engagement along the project. This is attributable to a range of factors:

- large amount of technicalities

- complex procedures
- lack of standard common language between partners coming from different fields of expertise
- low interest for topics going beyond the lifetime of the actors (persons)

In particular, two projects mentioned a perceived confusion within the climate community regarding the notions of risk, hazards and resilience. Also, metrics and metadata are not always shared within the community. As in Deliverable 1.1, we also registered the "missing standardisation of information" as one of the highest technical barriers. Two projects pointed conceptual misunderstandings even within the scientific community regarding the notions of risk, hazards and resilience. Also, metadata and metrics are not always shared and accepted by all. The technical complexity of projects was also mentioned as pressing difficulty. In particular, the downscale of climate data to high resolution local models and the inclusion of inputs from different disciplines represented a difficulty some consortia had to face. Projects mentioned quality and data availability increased in the last decade. Scientific and technical difficulties vary according to the type of user: engineer-oriented clients and consultancies are more quality demanding than regulators and public authorities.

Among the private sector companies interviewed, new players are entering the market performing applied research in-house (e.g. consultancy firms). The majority of private sector stakeholders mentioned data reliability and conflicting time priorities as main barriers. Despite their large expertise, public climate services providers are often not aligned at time constraints set by private sector's clients. This time mismatch generates a lower average quality. Finally, co-production partnerships indicated transparency, credibility and lack of standards as the most impactful barriers in their everyday work.

Finally, the political landscape was frequently mentioned throughout the interviews: given the challenges posed by climate change related topics, investors, clients and users require stable and consistent environments to engage with climate-related topics.

8.2 Main messages – quality assurance

Key points

- Quality assurance (QA) is not only a matter of control, but just as much of *communication*
- The more a CS involves tailoring, non-climate data, advice and training, or the more the user lacks expertise in climate and/or risk analysis the more QA should go beyond the statistical properties and origins of the climate data, and consider also linking feasibility with non-climate data as well as the service delivery process
- Broad scoped QA (beyond climate data properties) greatly benefits from or even requires interactive approaches such as co-design of the CS with the user – the so-called *open model*
- Quality uncertainty of CS concerns both the *performance uncertainty* (party covered with traditional QA) and the *product fit uncertainty* (addressed by broad scoped QA)
- Many CS providers are aware of the need for broader scoped QA, but point at the lack of available – applicability proven – indicators
- Broad scoped QA, including versatile feedback systems, can also support innovation in CS
- Broad scoped QA can include, where appropriate, the review of linking feasibility with non-climate data; for example the very thorough QA development efforts in the COPERNICUS C3S programme merit – at least exploratory – extensions with respect to selected non-climate data
- Social learning both among CS users and CS providers should be promoted in a systematic way as a means to improve matching of CS offers and needs, and thereby support the market growth of CS
- The enablement of social learning is one of the reasons to review possible time limitations of confidentiality conditions of publicly funded CS developments

QA has both an internal and external function, and should not only impose but also listen. As clarified in Chapter 5 QA is a *means of control* so as to ensure that quality of services meets relevant minimum standards for the envisaged customer groups. At the same time, as shown in Chapter 6, QA is a *means of communication*. It should inform, and preferably convince prospective users about the adequacy of the service for their purposes. An organisation can try to achieve a high degree of quality control, but that may come at the cost of less flexibility towards customer needs and a reduced ability to absorb larger innovations. In other words a strong focus on quality control risks to frame QA primarily as an internal function, supplemented by mainly outgoing communication ('this are our meta-data and these are the limitations'). Instead QA can also be built in a way allowing for significant and recurrent or continuous input from users, even if the business model is oriented towards automated standardized information delivery. Furthermore, from the interviews, both those related to business models and those about QA, became clear that a significant share of the climate services is better delivered in a so-called 'open model' (see section 5.3) in which interaction with the user is intensive and involving recurrent consultation or co-design. In that case the coverage of QA has to expand and its way of communication has to change. The ultimate conclusion is that in the open model QA can also became an issue for the user, thereby opening up prospects for linking

QA across value chains, which may be important to ensure that the social benefit of the entire climate service chain is maximized, rather than sums of segmented or private benefits.

From this discussion can be inferred that there should be better understanding of the fitness of QA approaches in relation to applied business models, and subsequently this better understanding should be well communicated to relevant actors. Furthermore, the function of QA in evolution and innovation of CS products should be better understood, and demonstrated.

From the various interviews, surveys and literature sources arises a picture that climate service providers tend to be well aware of the needs of CS product diversification in conjunction with open models. However, most CS providers have no clear ideas about what kind of (concrete) QA would be needed to support those business models. As a consequence QA tends to be still largely limited to climate data quality and origin, to some extent appended with feedback on satisfaction. Therefore as extension of the above suggested assessments regarding relevant functionality of QA in open models, concrete QA indicators need to be explored and tested.

In section 5.3 was indicated that promotion of learning among users, e.g. by better facilitating the sharing of such information, can improve uptake due to lowered effective uncertainty. By sharing information individual learning is broadened to social learning which is more effective in these emerging markets. To this end community of users could be established and facilitated by umbrella organisations as well as national and regional authorities. Next to the networking facilities as mentioned in D1.1 (section 3.6) a community of users would need more sophisticated information sharing instruments, e.g. linking the entitlement to development subsidies to obligations to share experiences. In this respect the rather generic use of confidentiality for results in the COPERNICUS C3S programme merits reconsideration. Also dedicated courses and competitive procurement (used in energy transition programmes) could be considered.

QA is already reasonably developed for upstream climate services, where national met-offices (NMS) play a dominant role. The QA efforts in COPERNICUS C3S set a role model for good standards for assurance of data quality and tractability. The application and communication of these standards merit to be further promoted by COPERNICUS and its partners. As next steps CS providers can try to extend the meta-data information into the realm of user data, e.g. population density, in order to better facilitate decisions on how to trade-off different optimal spatial and temporal resolutions for climate and non-climate variables.

Obviously when moving downstream the value chain and the non-data features (and non-climate data contributions) of climate services are getting more important QA procedures and information should be extended to cover these other characteristics of climate services. So far the indicators for these extensions are not well developed. CS providers should think about better measurement of these features. Development of such metrics will require involvement and testing with users.

8.3 Effects of legislation and regulation

Key points

- Many EU Member States have legislation in place, especially in relation to land use, urban planning, water, and physical infrastructure, that obliges or at least strongly recommends to account for effects of climate change
- Yet, the legislation or guidelines leave often a lot of leeway to the sector or regional decision makers how rigorous and with what kind of information the climate change impact and adaptation assessment is carried out, and consequently there is no strict obligation to use climate services or assure a certain quality level of these services – hence standards are set by how the practice develops
- In the finance sector emerges interest in defining national and international reporting obligations with respect to exposure to climate risks, which encompasses both asset value risks of climate (mitigation) policy and various value loss risks related to climate change impacts

From the review in chapter 7 of German and British legislation with respect to land use planning and from the quick view of Finnish regulation on accounting for climate change in urban planning / municipal zoning can be inferred that these laws and guidelines are strong enough to incite action, but often seem to lack follow-up guidelines to ensure good quality implementation. Either for reasons of subsidiarity of local governments or due to legislative complexity and related risks of conflicting signals local and regional actors are often left with considerable degrees of freedom on how exactly climate change is taken into account and to what extent scientifically underpinned information and data is used.

In the finance sector can be witnessed a rising number of signals that supervisory authorities are preparing for issuing guidelines on disclosure of climate related risk exposure (chapter 2; chapter 7). Yet, at the same time it becomes clear that the finance sector tends to cast climate risks in a different way than what climate experts would expect (presentation by Kivisaari in EU-MACS seminar; some WP2 interviews), i.e. lumping together climate policy effects and climate change effects or even broader casting it as a sustainable transition related set of risks *and – more particularly – opportunities*. Hence somewhat similar to the dynamics in land use planning the sector will most probably respond constructively to meaningful legislation on climate risk disclosure. Yet, there are reasons to be concerned about the adequacy of the climate data used and the way of use, if follow-up guidelines are not pertinent enough. On the other hand this awareness raising process requires from CS providers the ability and the skills to listen well to the sector and initiatives to co-develop guidelines for suitable climate and climate risk data for and with the financial sector.

8.4 Relation with innovation and CTA approach

As became apparent in the interviews with climate service providers conducted for Tasks 1.2 and 1.3 the CS field is characterized by a high pace of innovation. Many activities concern climate services development rather than (regular) climate services delivery. A part of the activities has still a high share of research input, whereas others concern already more focused product development and piloting. Also commercial climate service providers indicate that the innovation effort is very substantial. Also climate services which can be regarded as a regular product, may still comprise innovation elements inter alia due to the need for tailoring to the clients' needs.

In order to facilitate the work in Tasks 1.5 and 1.6 (Deliverable 1.4) this section considers how the findings with respect to QA are relevant for the innovation perspective in EU-MACS. The role and potential of innovation is studied in the framework of Constructive Technology Assessment (CTA). Within CTA a so-called multi-layer perspective is applied, in which three levels of activation of innovation are identified, being: regime, landscape, and niche. The concepts are summarized in the table below. Deliverable 1.1 section 3.6 provides a more generic review of innovation aspects and also a review for each of the three layers with respect to market development.

TABLE 8-1 KEY TERMS IN THE TYPECASTING OF INNOVATION DYNAMCS IN EU-MACS

Layer	What does this mean?
Multi-layer perspective (MLP)	A multi-layer perspective helps to "inquire how the context of innovation journeys influences the dynamics of innovation" (Rip 2012).
Regime	In a multi-layer perspective referring to a set of rules, practices and institutions structuring the further development of a technology (and service, market, policy).
Landscape	Backdrop of opportunities and constraints for technology, service, market, and policy development.
Niches	In a multi-layer perspective referring to protected spaces for vulnerable novelties, shaped by requirements for protection and some boundary maintenance; carved out in selection environments, e.g. by benevolent selectors (sponsors of start-up firms); lead to mini-paths and a lock-in.

Regime:

In relation to QA the following legislation and governance areas are relevant:

- Adaptation planning and possible obligations by sector (notably for urban planning, water management, and new buildings)
  - The use of CS is often not explicitly stipulated in the law, but may be implied by it or in practice some early adopters set a standard (H8)
- Critical Infrastructure Protection (CIP) – motivated by concerns about societal resilience and economic robustness ('continuity planning') the EU has adopted directives on CIP (2008/114/EC), obliging Member States to assess and monitor the resilience of critical infrastructure with respect to natural and human induced hazards
  - CIP related policy implementation often involves also obligations regarding monitoring and preparedness reviews, implying the development of support tools (e.g. FP7 project INTACT)
- The UN agreement on DRR, the so-called Sendai Framework for Disaster Risk Reduction (UNISDR 2015), which inter alia includes reporting obligations on DRR preparedness (while accounting for climate change) and incurred damage for all member states
  - The reporting obligation can be understood as also inciting to better analyse relations between the severity levels of extreme weather and climate conditions and resulting damage levels for various vulnerability levels

- The EU INSPIRE directive (2007/2/EC) on opening of publicly funded spatial data for third party use (without charges for the data as such)
    - A recent report on benefits of open data in Europe (European Union 2017) exemplifies the significance of open data policies for promoting service innovation and lowering information cost (also due to incited standardization)
- EU R&D programmes
    - The COPERNICUS C3S programme dedicates significant amounts of resources to quality assurance information and underlying procedures applicable to all involved data sets
    - In H2020 (SC, … chapters), LIFE+, and JPI Climate especially attention for developing and piloting CS for sectors and application, where the market seems to have difficulties to initiate sufficient action (such as for climate change and health)

Landscape:

There are numerous trends and science and technology developments and promote and shape the development and use of climate services. At least the following seem worth mentioning:

- Several interviewees regarded *seamless prediction* as an important development. Seamless prediction means that one modelling approach is used to cover forecasts across a range of time frames (e.g from days to several months or even more stretched ranges), rather than having different temporal category forecasts each based on different modelling approaches. As a consequence more flexible CS product offers could be made tailored to specific user needs. Also more integrated CS products could be offered considering effects at different temporal and spatial scales. However, this means increased product complexity for users, while similar seamlessness is as yet not achieved for non-climate variables;
- Long term climate modelling is still progressing in refinement and coherence, e.g. raising spatial resolution capabilities and abolishing the need for running regional climate models framed within global climate model scenarios; also further inclusion of interaction with large water bodies and with the biosphere (e.g. large forest areas, soils);
- The growth in computational power and data transmission capacity is very important for use of larger and/or more sophisticated models, but just as well to enable better visualization in order to make projected impacts more understandable for users and/or better linkable to users' data; also the expansion of cloud services should be mentioned in this respect, making large data storage capacity more affordable (and thereby indirectly enabling some types of quality enhancement)
- Remote sensing offers not only a growing variety in observation technologies at various scales (satellites, mini-satellites, long range and short-range drones), but is also improving its capabilities to cover (consequences of) human activities; the latter features may help to improve and extend linkage options between climate and non-climate data; yet, all these new combinations imply also significant quality assurance challenges;
- Visualization is moving into 3D application (e.g. relevant for urban climate issues) as well as widening the use of dynamic representation (video); this enables the representation of multifaceted scenarios in timewise compact formats for policy makers;
- Even though the development of the senses of urgency regarding climate change is not a linear process, one can witness that ever more business sectors start to take climate change seriously, i.e. the CDP network (https://www.cdp.net/en), started as carbon disclosure, but now extending to climate change effects);
- Uptake by insurance sector and their translation into policy conditions, and new products, etc.

- Integrated sustainable and climate proof urban planning

Niches:

With respect to climate services provision we have noted some fairly recent – promising – developments, which seem capable of demonstrating important organizational innovations and aim at alleviating important shortfalls in the current CS market.

- Cooperative structures emerge which aim to better exploit complementary knowledge, capabilities and skills; cooperative structures emerge among CS providers, mixtures of CS providers and users, as well as CS users only. The viability of these cooperative structures often rests on the improved efficiency or effectiveness of constituent CS (part)products of the partners, whereas the network as such may in the first require resources. On the one hand these structures need organizational and possibly institutional innovations, whereas on the other hand these can enhance uptake of CS innovations;
- Somewhat related to the previous point is the emergence of new types of brokerage with respect to climate services; on the one hand demand side led rather than supply side led brokerage is dearly needed, whereas on the other hand low threshold CS search and selection tools on internet are welcome to serve those that for whatever reason cannot use a brokerage service; the building of trust both for both CS users and providers is an important element to make brokerage abound and to this end innovative certification and endorsement processes could be helpful;
- In various domains of environmental observation and monitoring (weather, hydrology, natural hazards) citizen involvement is an emerging – yet largely still experimental – trend, usually referred to as 'citizen science and observation' or 'participatory observation'; initiatives are hitherto often local; on the one hand this approach has significant quality assurance challenges, while on the other hand it has also the potential to enhance observation and forecast precision for some applications, and enable new more personalized services; it may also help to raise environmental understanding and willingness to act (yet there are also many pitfalls in this respect – see section 5.3)

9 CONCLUSIONS AND IMPLICATIONS FOR OTHER WORK PACKAGES

9.1. Generic remarks and recommendations

It is important to acknowledge the variations in interpretation or expectations with regard to the term climate services across user sectors on the one hand and CS providers on the other hand. Some may like to cluster it into 'environmental risks', while others lump together the impacts of climate change (e.g. sea level rise or increased drought risks) with impacts of climate policy (emission trade, carbon taxes, insulation norms), while still others are mainly interested in better coping with climate variability (seasonal forecasts).

At the same time it is also important not to blur the remit of the project nor the in this project adopted – already quite broad scoped – delineation of climate services of the EU Roadmap. So, climate services in this project are always understood as being somehow firmly rooted in observations and/or projections of climatic conditions, in many cases reprocessed and enriched with other data and information. This means for example, that climate services can contribute to the generation of product carbon footprints (especially relevant for products with significant natural inputs such as food products), but the resulting carbon footprints fall outside our definition of climate services. Similarly, emission trade systems, carbon offset services, etc. may need *climate services as input*, but the resulting products (and most of the value chain) fall outside the remit. The logic behind this delineation is the *bulk* of the information flows for these concepts has nothing to do with the value chains of climate services, whereas these may also be subject to many policies totally outside the realm of climate services. A similar kind delineation could be applied to logistic services or public health services. Some of these may even have a significant input from climate services, for example in case the resilience of critical infrastructure is an important element, but again the resulting products and most of the value chains fall outside our remit.

For CS providers user specific perceptions of climate services may cause dilemmas on how much product diversification should be accepted (possibly through partnerships) and to what extent they should clarify current and prospective users when in some respect related service products nevertheless deserve more separate treatments in certain stages of decision preparation processes. In some cases a more fundamental discussion may even be necessary, for example if blurring of impact categories may well lead to blurring of risk mechanisms and related evaluations.

9.2. Stakeholder engagement – WP2-WP4

From the assessments of Task 1.2 and Task 1.3 became apparent that with respect to CS users the following aspects merit attention in the interactive explorations with stakeholders in WP2, WP3, and WP4:

- To what extent is a (prospective) CS user able to specify needs with respect CS use, and to what extent are these needs already specified?
    - This may relate to awareness raising activity, but it may also relate to measures that reduce product performance uncertainty and product fit uncertainty
- To what extent is a (prospective) CS user dependent on other CS users or on other actors affecting the use of climate services; on the one hand this may lead to coordinated co-design for groups of users, it may also lead to reconsideration of the CS acquisition process, i.e. coordinated or centralized for a sector or regional cluster of users;
- To what extent should the organisation of the CS provision (partnership or one actor; public or private) be considered in the interactive explorations, and at what stage; also the consideration to first use CS brokerage or rather go for direct selection merits attention;

- To what extent are (prospective) CS users willing to share input and output information with respect to CS delivery, and if so with what kind of parties and under what conditions;
- How see (prospective) CS users the different options for individual and social learning with respect to CS use.

9.3. Innovation – WP2-WP4 & WP5

From the assessments of Task 1.2 and Task 1.3 became apparent that with respect to CS users and supporting stakeholders the following aspects merit attention in the interactive explorations with stakeholders in WP2-WP4, and in the synthesis in WP5:

- Check for other significant innovation trends going on in the focus sectors, and to what extent these (can) connect with CS innovations, such as blockchain technology or 3D urban development planning; also social trends and innovations can count;
- Check the interest and willingness among CS users and providers to explore new QA indicators, related to CS delivery process or linking feasibility of climate and non-climate data;
- Assess the extent to which current regulation or guidelines is inciting innovation CS use or at least supporting uptake of improvements in CS; and consider options for regulations or guidelines that reinforce the innovation drive (without discouraging overall uptake of CS)
- Check whether interest in a particular class of CS (e.g. seasonal products) can function as launching pad for interest in other classes of CS, and whether innovations in CS (such as seamless prediction) may promote such extensions of the used CS portfolio

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ANNEX 1: ORGANISATIONS INTERVIEWED IN RELATION TO RESOURCING

- 2DegreesInvesting Initiative – http://2degrees-investing.org/#!/
- Acclimatise - http://www.acclimatise.uk.com/
- Agro-Adapt - https://www.cmcc.it/it/projects/agro-adapt-service-for-local-and-economy-wide-assessment-of-adaptation-actions-in-agriculture
- Allianz Global Investors - http://www.allianzgi.it/it/Pages/default.aspx
- Allianz Climate Solutions GmbH - http://acs.allianz.com/en/
- Amundi Asset Management - http://www.amundi.us/?nr=1
- Avanzi SRL – www.avanzi.org
- AXA Global P&C - https://www.axa.fr/
- Business Integration Partners (Bip) - https://www.businessintegrationpartners.com/
- City of Helsinki – executive office - http://www.hel.fi/helsinki/en
- CLIM-RUN - http://www.climrun.eu/
- Climate Adaptation Services (CAS) - http://www.climateadaptationservices.com/en/
- Envirochange - https://enviro.fbk.eu/
- Ernst&Young - http://www.ey.com/it/it/home
- Etica SGR - https://www.eticasgr.it/
- EU-CIRCLE – www.eu-circle.eu
- EUPORIAS - http://www.euporias.eu/
- Finnish Meteorological Institute - http://en.ilmatieteenlaitos.fi/
- FloodRe - http://www.floodre.co.uk/
- Gaia - http://www.gaia.fi/
- GECOsistema SRL, Geographic Environmental Consulting - http://www.gecosistema.com/
- GREEN SURGE - http://greensurge.eu/
- MOEEBIUS – www.moeebius.eu
- MORE-CONNECT - http://www.more-connect.eu/
- MunichRe - https://www.munichre.com/en/homepage/index.html
- OASIS Loss Modelling Framework Ltd - http://www.oasislmf.org/
- SWICCA - http://swicca.climate.copernicus.eu/
- SWITCH-ON - http://www.water-switch-on.eu/
- Thetis SPA - http://www.thetis.it/it/
- UnipolSai Insurances, Unipol Group - http://www.unipolsai.com/en/Pages/default.aspx
- UrbanSiS – www.climate.copernicus.eu/urbansis
- Water-Ener-Cast (WEC) - http://www.climate-kic.org/projects/wat-ener-cast/
- WSP Group, UK Limited company – www.wsp.com

ANNEX 2: INTERVIEW GUIDELINES AND STRUCTURE OF INTERVIEWS

We conducted semi-structured interviews among the stakeholders included in the sample of interest. Interviews were flexible to guarantee to participants enough freedom to explain the functioning of their projects and activities. The so-designed conversations followed a guiding structure aimed at capturing the core components of business models: the sample of strategic choices, the creation of value, the network and the value detainment. Specifically, we tried to gather information on key issues (as by Hanshaw and Osterwalder, 2015):

- value proposition
- key partners
- key activities
- customer relationships
- key resources,
- channels,
- cost structure (if any) and
- Revenue streams (if any)

Depending on the context and the type of stakeholder, we stressed more on one component or another. This is the case for "revenue stream": public funded projects are, in fact, subject to policies that might prohibit the commercialisation of the product or service, while private companies and co-production partnerships may be profit-oriented.

The type of data collected through this methodology is typically qualitative. We analysed them through a content analysis. The guideline questions are presented at continuation.

Interview Guidelines

Q0. Please, tell me more about ___. Throughout the chat, we are getting more specific on different aspects.

Q1. What is the value proposition of ____ ?

Q2. How is ___ using climate-related information? Is __ a provider, a purveyor or both of climate information? [note that here we normally explain what we mean before asking and trying to contextualise]

Q3. What are the channels ___ is using to gather the required information that will serve as inputs for the service?

Q4. What are the main data sources?

Q5. Do you normally pay for input data? If yes, how much? (if they are not willing to share, we normally ask them to give us an idea in percentage of the information acquisition costs)

Q6. (if a purveyor of can't define) What are the main providers of ___ ?

Q7. Who are the users/ customers __ is targeting?

Q8. (if they have not identified any specific user) How are you planning to identify your final user/customer?

Q9. How is __ sharing the information?

Q10. Is ___ publicly available? Is __ selling the created information/model/product?

Q11. What was the main source of funding of ___?

Q12. Please describe the evolution overtime of this market according to your experience with __? Is there a growing, steady or decreasing interest in these topics?

Q13. Which are the most common difficulties you face throughout the development of your service/product? Are there any cultural, social, psychological or economic barriers?

Q14. (in case of EU-funded projects) Do you have interactions with other projects? If yes, please describe how. Are they European only? If not, how do you interact with beyond-EU institutions/projects/activities?

Q15. (in case of private sector companies) In terms of competitors, please describe the evolution overtime and how you distinguish from the others? What is your value-added?

Q16. Are you aware of any other interested service/product/project currently implemented or under development?

Thematic coding of answers

N1. Positioning in CS field
• Provider
• Purveyor
• User
 	
N2. Type of actor
• Co-production partnership
• Private sector
• Public sector
	N3. Sectors
	• Agriculture, Forestry and Food Security
	• CO2 abatement
	• Consultancy
	• Energy
	• Financial services (banking and investments)
	• Health
	• Insurance
	• Sustainability-related
	• Tourism
	• Urban planning
		N4. Outputs
		• Climate projections and observations
		  ○ Global
		  ○ downscaled
		• Energy (incl. renewables)
		• Environmental consultancy
		• Financial services (incl. asset management)
		• Impact evaluation
		• Product development
		• Methodology and indicators development
		• Risk assessment

N5. Financial resources • Clients • Mixed • Public money	**N6.** Geographical scope • Continental (EU) • Global • Local • National	**N7.** Inputs • Data from other (pub.) organisations • Data from private companies • Primary data • Data from clients
N8. Commercialisation strategy • Products and services under license • Ad-hoc products and services • Open data and free products • Freemium	**N9.** Communication channels • Public reports • Platforms • Newsletter • Demonstrators • Events	**N10.** Development stage • Exploratory activities • Demonstrator/pilot • Fully operational

ANNEX 3: ORGANISATIONS INTERVIEWED IN RELATION TO QUALITY ASSURANCE AND QUESTIONS ASKED

Acclimatise Ltd – United Kingdom

Deutsche Wetterdienst (DWD) – Germany

German Climate service Centre (HZG-GERICS) - Germany

Ilmatieteen laitos (FMI) – Finland (2x - operational services and services development separately)

Joanneum Research (JR) - Austria

The Climate Data Factory (TCDF) - France

Interviewees had received a request for an interview, which included a brief explanation of the EUMACS project and the purpose of the interview. The questions and an informed consent form were sent in advance. Typical duration of the interview was 50 to 70 minutes. The interviews were recorded. A form with answers summarized from the interview was sent to the interviewees for review and consent. The individual forms and recordings are not freely available.

………………………………………………..

Introductory questions providing context

1. Please indicate the scope of your services (particular types of products and particular types of users / clients)
    a. do services mainly encompass climate data, or can they also include (or even mainly consist of) visualisation, consultancy, education, etc.?
2. Please indicate the cumulated experience with these types of service provision – overall, and whether significant product sections or user groups are quite new (less than ~18 months)
3. Can you indicate approximately what share of the climate service products is still in some kind of experimental stage ('beta version')

Quality management and assurance

4. How would you define quality in case of climate services? – is the quality notion differentiated for different climate services?
5. Do you have in your organisation a formalized system for checking and reporting statistical and database properties of datasets used for climate services?
6. Apart from the statistical and database properties, what other aspects do you regard as important with respect to quality assurance of climate services? – do you (systematically) observe these other aspects?
7. Does your organisation use quality certification protocols (e.g. ISO) for building blocks of climate services?

The significance of quality for actual service delivery and user interaction

8. Do you include information on quality ratings or notions when offering climate services to potential users?
9. Does interaction with potential users and service delivery to users include inquiries about quality

perceptions of the user?

10. Would you expect that **appropriateness** of the climate service (in terms of contents and format) from the point of view of the user, notably regarding the compatibility with the user's other data, risk concepts, etc. is a key aspect of quality? – are you assessing this (perhaps jointly with the user) when offering and/or providing a climate service?
11. Would you see possibilities to extent internal quality assurance indicators to encompass (aspects of) compatibility at the user side?
12. Is quality assurance dependent on resourcing and business models at the side of climate service provider or purveyor?
13. Is quality assurance dependent on resourcing at the side of climate service user?

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ANNEX 4: T1.1 SURVEY QUESTIONS RELEVANT FOR QUALITY ASSURANCE AND SUMMARY OF RESULTS

Climate service providers

8. Does your organisation operate a quality assurance process in relation to the supplied climate information?
YES / NO

9. Does this system include:

- Statistical properties of datasets
- Declaration of the sources of the datasets (observations, simulations)
- Declaration of post-processing steps (bias corrections, interpolation, etc.)
- A systematic production and maintenance of metadata per dataset
- Some kind of certification
- Other

10. Do you provide meta-data on datasets and other information to (prospective) users?

- Upon request
- Standard practice
- Usually not
- Other

11. Does your organisation operate a quality assurance process in relation to the supplied climate information?

- no
- yes

12. Do you offer advice and/or tools to users to evaluate the fitness-for-purpose of climate information?

- Yes
- Yes, but evaluation is joint effort of CS provider and (prospective) user
- Yes, that is to say we do that in-house, without involvement of the user
- No

18. Please let us know, which technological and scientific barriers you have already faced in relation to the selected service? This category also includes scientific barriers, as many of them are also related to technological constraints. Please rate their importance from 1 (low) to 5 (high).

(end) users of climate services

65. What, in your opinion, does 'quality' refer to in your choice of climate service providers, and how would you rate it in terms of importance from 1 = low to 5 = high? *

- The eventual usefulness of the information in our own processes
- The serviceability of the provider regarding information transfer, applicability, and further advice
- The fitness of the provided data and other information for joining with our own data and information (spatial and temporal resolution, statistical properties, proximity to variables of interest)
- The cost of acquisition and use of the climate services …

ANNEX 5: DESCRIPTIONS OF DATA QUALITY ASSURANCE PROCEDURES

Essential Climate Variables

The list of Essential Climate Variables (ECV, Table1) was determined in wide collaboration of data providers and users (GCOS, 2010). Several of these ECV's are for the needs of expert users and researchers and to a lesser extent for end users of climate information. As regards the atmospheric surface ECV includes: air temperature, wind speed and direction, water vapour, pressure, precipitation and surface radiation budget. From the terrestrial domain we limit our discussion to snow cover and land cover.

In their updated implementation plan the Global Climate Observing System published also climate monitoring principles (GCOS, 2010, Appendix 4) which can be considered as generic quality assurance methods for observation. Only few countries have reported their status on GCOS national observation systems.

Table 1: Essential Climate Variables that are both currently feasible for global implementation and have a high impact on UNFCCC requirements

Domain		Essential Climate Variables
Atmospheric (over land, sea and ice)	**Surface:**[8]	Air temperature, Wind speed and direction, Water vapour, Pressure, Precipitation, Surface radiation budget.
	Upper-air:[9]	Temperature, Wind speed and direction, Water vapour, Cloud properties, Earth radiation budget (including solar irradiance).
	Composition:	Carbon dioxide, Methane, and other long-lived greenhouse gases[10], Ozone and Aerosol, supported by their precursors[11]
Oceanic	**Surface:**[12]	Sea-surface temperature, Sea-surface salinity, Sea level, Sea state, Sea ice, Surface current, Ocean colour, Carbon dioxide partial pressure, Ocean acidity, Phytoplankton.
	Sub-surface:	Temperature, Salinity, Current, Nutrients, Carbon dioxide partial pressure, Ocean acidity, Oxygen, Tracers.
Terrestrial	River discharge, Water use, Groundwater, Lakes, Snow cover, Glaciers and ice caps, Ice sheets, Permafrost, Albedo, Land cover (including vegetation type), Fraction of absorbed photosynthetically active radiation (FAPAR), Leaf area index (LAI), Above-ground biomass, Soil carbon, Fire disturbance, Soil moisture.	

Climate Monitoring Principles

Effective monitoring systems for climate should adhere to the following principles:

1. The impact of new systems or changes to existing systems should be assessed prior to implementation.
2. A suitable period of overlap for new and old observing systems should be required.
3. The results of calibration, validation and data homogeneity assessments, and assessments of algorithm changes, should be treated with the same care as data.
4. A capacity to routinely assess the quality and homogeneity of data on extreme events, including high-resolution data and related descriptive information, should be ensured.

5. Consideration of environmental climate-monitoring products and assessments, such as IPCC assessments, should be integrated into national, regional and global observing priorities.
6. Uninterrupted station operations and observing systems should be maintained.
7. A high priority should be given to additional observations in data-poor regions and regions sensitive to change.
8. Long-term requirements should be specified to network designers, operators and instrument engineers at the outset of new system design and implementation.
9. The carefully-planned conversion of research observing systems to long-term operations should be promoted.
10. Data management systems that facilitate access, use and interpretation should be included as essential elements of climate monitoring systems.

Furthermore, satellite systems for monitoring climate need to:

11. Take steps to make radiance calibration, calibration-monitoring and satellite-to-satellite cross-calibration of the full operational constellation a part of the operational satellite system; and
12. Take steps to sample the Earth system in such a way that climate-relevant (diurnal, seasonal, and long-term interannual) changes can be resolved.
13. Thus satellite systems for climate monitoring should adhere to the following specific principles:
14. Constant sampling within the diurnal cycle (minimizing the effects of orbital decay and orbit drift) should be maintained.
15. A suitable period of overlap for new and old satellite systems should be ensured for a period adequate to determine inter-satellite biases and maintain the homogeneity and consistency of time-series observations.
16. Continuity of satellite measurements (i.e., elimination of gaps in the long-term record) through appropriate launch and orbital strategies should be ensured.
17. Rigorous pre-launch instrument characterization and calibration, including radiance confirmation against an international radiance scale provided by a national metrology institute, should be ensured.
18. On-board calibration adequate for climate system observations should be ensured and associated instrument characteristics monitored.
19. Operational production of priority climate products should be sustained and peer-reviewed new products should be introduced as appropriate.
20. Data systems needed to facilitate user access to climate products, metadata and raw data, including key data for delayed-mode analysis, should be established and maintained.
21. Use of functioning baseline instruments that meet the calibration and stability requirements stated above should be maintained for as long as possible, even when these exist on decommissioned satellites.
22. Complementary in situ baseline observations for satellite measurements should be maintained through appropriate activities and cooperation.
23. Random errors and time-dependent biases in satellite observations and derived products should be identified.

Weather station observation data

Quality Assurance aims to ensure that data are consistent, meet the data quality objectives and are supported by comprehensive description of methodology. Quality assurance of historical climate information is currently based on regularly updated, comprehensive set of WMO standards and guides in observation systems and climate service processes. In NMHS in wealthy countries the basic in-situ observations and the quality control systems follow these standards quite well, but in developing countries insufficient quality may originate from unreliable observation processes due to lack of resources. Noteworthy, that due to various political or economic reasons there may be periods of poorer availability or quality in the historic climate data, even in present day wealthy countries e.g. in Europe in relatively new states in Balkan.

Data from observation stations

Quality of in situ meteorological observations are in principal regulated by WMO Standards and related guides[21]. The latest update of *Guide to Meteorological Instruments and Methods of Observation* (WMO-no8, 2014) includes extensive part of quality assurance and management of observing systems. From the climate service perspective, the quality assurance of meteorological observations as such are based on these internationally implemented standards.

Climate services are often based on time series of observations and NMHS should ensure data homogeneity. The quality problems with observational data arise from changes in observation techniques, data management processes and observations station network over decades, which lead to homogeneous time series. Furthermore all the historical observations data are not yet digitized, which limit their use in climate services. WMO has also prepared *Guidelines on Climate Metadata and Homogenization* (WMO/TD-No. 1186). However, there are no widely accepted one homogenization method for climatological time series, instead homogenization methods of time series are continuously under research and further development. A review study of Ribeiro et al. (2015) on homogenization methods provides a summary of conclusions and lessons learned from the use of various methods. Especially precipitation data requires still much greater effort, as their variability is spatially more complex than for instance temperature data. Because it is not self-evident that homogenization can produce time series that are reliable, many researchers prefer using only selected, continuous long time series without homogeneity problems.

The amount of open climate data is rapidly increasing, important part of opening the data for public use is the quality assurance of the data including availability of metadata. (*See also separate chapter xx on Open data)*

Remote sensing data

Especially in Europe, most satellite programs are international co-operations and satellite data is therefore provided by international institutions, such as EUMETSAT and ESA. National institutions, such as NOAA, NASA, JAXA, ISRO and CMA, do also contribute data. Satellites provide a relatively new form continuously evolving data; homogeneous time series over years need constant reprocessing and validation. Observations from instruments onboard satellites can be disseminated as products based only on satellite-

[21] https://public.wmo.int/en/resources/standards-technical-regulations

based observations (e.g, most terrestrial ECVs) or they can be assimilated with other observations into reanalysis and other models (e.g., most upper-air and composition atmospheric ECVs). At present, only few satellite-based time series span thirty years, but this will change in near future as time passes.

Weather radars networks have been mostly national programs run by NMHSes, but there are a number of either bilateral or more widely international data exchange programs such as OPERA in Europe (Huuskonen et al, 2014). When data from disparate radar networks is used as input for an international radar mosaic, all differences in quality become clearly visible. This has encouraged NMHSs in joint QA projects.

For climate services radars provide vital additional information about precipitation, because the spatial distribution of rain varies remarkably especially in case of rain showers and rain gauges in weather station rarely catch the most extreme precipitation. However, currently radars cannot provide correct information on amount of precipitation due to several physical and methodological reasons such as attenuation of radar beam in heavy precipitation cases and accuracy of radar equation to interpret radar signals into amount of precipitation. Therefore the radar precipitation estimates need to be validated against rain gauge observations case by case.

A new source of remote sensing data are the instruments installed at unmanned aerial vehicles (UAV; a.k.a. drones). At present, they are most useful in providing data for case studies, e.g. for weather hazard cases for insurance. So far, no operative long-term observations systems utilizing UAV exist, so they do not yet provide observations for homogenous time series. This, of course, might change in future.

Weather observation made by citizens have earlier been considered to be too unreliable because they typically don't follow the WMO standards. However, lately their value have been understood as complementary information. Citizen observation may provide really important information especially about small scale phenomena such as hail or tornados, which seldom are caught by weather stations. Furthermore, citizen observations may provide useful information about climatic conditions e.g. in locations where extreme temperatures take place and which are different from the WMO standards for the good quality observation station. These non-standard conditions may be quite useful for the users in their applications, but special attention needs to be given to the users about uncertainties related to the citizen observations.

Climate statistics and declaration of statistical properties

The Guide to Climatological Practices (WMO, 2011) describes standard climatic products such as production of climate normal statistics, which are based on 30 year time series of homogeneous data. Furthermore it describes most common statistical distributions and analysis methods for climate dataset.

The Guide to Climatological Practices points out the importance of quality assurance under chapter discussing dissemination of climate information (p. 6-4) as follows:

Providing relevant information for use in preparing and implementing national policy and strategies places several demands on the information personnel:

(a) Historical information must be collected, subjected to quality control, archived and made accessible in a timely manner;

(b) Assessments of the climate data and information must be related to the needs of the decision-makers and those responsible for implementing decisions;

(c) Interpretations and presentations of climatic data, information and scenarios, and the degree of confidence in the interpretations, must be meaningfully communicated to users who may not be technically knowledgeable about climate;

(d) Coordination with other public agencies, academic institutions, private interest groups and programmes is often necessary to answer multidisciplinary questions concerning national, sectoral and community vulnerability related to climate variability and change.

Under chapter discussing marketing of climate service (6-5) the Guide raises up the quality assurance as follows:

Characteristics of an effective marketing programme include:

(a) Focusing on user needs by gaining a clear understanding of the user's problems and requirements and how the climate information is used;

(b) Training customer service personnel to become attuned to customer needs and wants;

(c) Selecting a target market;

(d) Promoting the benefits of climate services and products to the target sector;

(e) Developing a product or service for a need of the user and promoting its application to solving the user's problems;

(f) Promoting the professional skills of climate service personnel;

(g) Deciding on methods of product accessibility or delivery and making alternatives available to the user;

(h) Evaluating the economics of the products and services;

(i) Informing users through promotion and public relations;

(j) Monitoring user satisfaction and assessing service performance and marketing efforts;

(k) Ensuring credibility of climate services by being transparent about the reliability and limitations of the products and services offered.

A separate, more concrete "Guidelines on quality management for climate services" which aims toward quality certified climate services. So far, in NMHSs the ISO9000-standards have mainly been taken in use in weather services, but the aim is gradually to take them in use in climate services, as well.

Besides quality standards designed for climatological practices, other quality assurance policies can also be followed. E.g FMI climate service also obtained the quality assurance of Official Statistics of Finland, which follow the quality standards of EuroStat: European Statistics Code of Practice[22].

Conclusion: In principal quality assurance has been recognized to be an essential part of climate service processes. However, there is no information on how well climate services are able to follow these standards and guidelines.

Gridded data

The meteorological observation station network is sparse and does not always meet the spatial resolution needs of the clients. Therefore meteorological community has prepared various gridded data sets, typically NMHS can provide their own national gridded data sets. Furthermore, there are also gridded data sets

[22] http://ec.europa.eu/eurostat/web/products-manuals-and-guidelines/-/KS-32-11-955

and databases that cover wider areas such ECA&D[23] in Europe. The gridded climate data sets have typically been produced by kriging-interpolation method within research or development project and *the quality assurance of gridded data is based on peer review scientific publishing process*. Typically gridded dataset have been used in other sectors in their climate impact research and the users are guided to study these publication and use them as a reference. For instance, Haylock et al. (2008) state about uncertainty of EOBS-gridded data set: "Interpolation uncertainty is quantified by the provision of daily standard errors for every grid square. The daily uncertainty averaged across the entire region is shown to be largely dependent on the season and number of contributing observations". The uncertainty of gridded data varies also over decade due to changes in observation network and homogenization. Thus, the use of gridded data requires advanced users.

The spatial and time resolution of gridded data sets typically meet the demand of many sectors. However, in certain application e.g. in urban planning very fine resolution and sub-daily gridded data is needed. In this case the solutions are model simulation. *The quality assurance of model simulations are again based on scientific reporting processes.*

The use of re-analysis instead of observations is increasing among researchers, because they cover areas with lack of observations and these dataset include comprehensive set of meteorological parameters. The use of re-analysis data sets requires advanced user and therefore it is not probable the typical end user of climate services would start using them, but climate services can utilize outputs of these international centers[24]. There are no standards for re-analysis, instead re-analysis methods are continuously further developed. The quality assurance of re-analysis are based on scientific reporting processes. According to Gregow et al. (2016) users of re-analysis wish for better characterization and communication of the uncertainties and limitations of the reanalysis data. The users also acknowledge that they need support to better understand the re-analyses.

Seasonal predictions

The accuracy of seasonal prediction is still very modest in Europe and therefore the use of the seasonal prediction is as yet quite limited, though nevertheless gaining popularity in some sectors, such as electricity supply and some crops. The quality of seasonal predictions can be assessed by verification, but that is not really adequate. We should also evaluate the use of the seasonal prediction in decision making process. There is a WMO recommendation (WMO 2002) for the verification of forecasts.

Application examples:

- In the common Nordic electricity wholesale market (NordPool) the forward price of electricity is based on econometric estimations using climate monitoring information (precipitation in Norway, temperature in Finland) and seasonal forecasts.
- Tourism: snow cover – beginning of the winter season, snowfall and temperature for artificial snow.

Decadal and multi-decadal scenario data

Quality assurance for predictive climate scenarios and broader analyses derived based on them is fundamentally different in nature when compared to other climate services. This is because the impossibility of meaningful validation. The long time scale of predictions makes direct validation by observations

[23] http://www.ecad.eu/download/ensembles/ensembles.php
[24] https://reanalyses.org/node/122

impractical and the unprecedented nature of current climate change compared to earlier climatic shifts makes it and out-of-sample event in terms of verification (also, only proxy data is available for most of climate history). Model performance can still be evaluated according to their ability to reproduce historical climates, but this validation approach seldom is independent as models are also calibrated according to most of them. Widely accepted objective measures of quality of quality hence do not exist and the issue of quality becomes more dependent on its definition and also the use context. For climate scenarios, quality could be defined as ability to deliver scientifically sound predictive information that support decision-making under uncertainty. Accordingly the following three pillars can be identified as the basis for the broad quality evaluation and assurance of climate scenarios:

- **Scientific and technical rigor**: Climate scenarios should be produced using scientifically sound and technically reliable models that are based on up-to-date understanding and modeling of the Earth system.
- **Diversity:** Instead of relying on one model or scenario, uncertainty can be addressed and to some extent quantified by using multiple models and runs.
- **Transparency:** Assessing rigor and utilizing diversity requires transparency in climate model and scenario construction and communication.

These three pillars are in practice applied to a varying degree in current climate scenario production and refinement. Regarding global climate models, the Coupled Model Intercomparison Project (CMIP) has produced multi-model climate data in standardized format for the international climate research community including the IPCC assessments for over 20 years (Eyring et al., 2016). CMIP, currently going through its 6th phase (CMIP6), is open for global climate models that provide certain standardized control simulations (for detailed description of CMIP6 process, see Eyring et al. 2016). The idea has been to prefer diversity and inclusion over theoretical "quality" and not to impose strict performance criteria. Accordingly, the scenario sets within i.e. IPCC assessments give equal weight to all included models. Regional models are in general based on the output of global models and are thus susceptible to the same limitations regarding quality evaluation.

Looking at an individual model, there are some ways to evaluate the quality. Ability to reproduce observed historical climatic development can be considered as an indicator of the model's skill to represent the physical world. The amount of non-physical accessory configurations such as specific correction on energy flows or additional artificial variables is an indicator for how well the mathematical model itself captures the complexity of the atmosphere. Spatial resolution and the level of detail in the phenomena modeled are indicators of the level of sophistication of a model. While all these indicators can be used to evaluate models, none of them are alone or directly suitable proxies for quality in general.

Models can also be evaluated by statistically comparing them with each other. Outlier analysis can be used to filter models that deviate from the average significantly, indicating possible limits or problems within these models, at least for certain areas. While this is generally not a scientifically justifiable way to assess the fitness of the models (it possesses a risk of ignoring possible but unlikely exceptional outcomes) it can be a reasonable way to select models for regional use. Models are varied in their skill to represent different geographical areas, and often these variances follow model origins (i.e. Japanese model might reproduce Pacific climate well compared e.g. to climate over Europe).

Despite the problematic definition of quality, based on assessments from multiple lines of evidence it is in practice clear that climate models have improved over time . The level of sophistication and the ability to reproduce historic development have increased with new models and model versions (Flato et al., 2013). Climate scientists are quite confident about the ability of the models to produce general, system level knowledge of climate and climate change (Bray & von Storch, 2016). Confidence in assessing more detailed climatic characteristics such as clouds or precipitation or decadal level changes using current models is however significantly lower (Bray & von Storch, 2016).

In practice evaluation of models from technical quality perspective is a highly technical task that requires quite sophisticated expertise. The quality of climate scenarios - the main outputs of these models - can also be evaluated based on their usability from the user perspective. Here the availability, ease of access and understandability matter. There is evidence that climate scenarios are not utilized in their full potential (Pilli-Sihvola et al., 2015). Yet it should be noted that the uncertain nature and the impossibility of validation of climate models and scenarios inevitably limits their use especially in decision making relying on predictive information (Dessai et al., 2009).

Tailored climate services

Typically there are very few mass products in climate service – mainly generic information on public www-pages. The real benefit of climate services realize in tailored climate services. There can be some concepts of tailored services, but typically services need to be tailored for specific location and time frame to be feasible for the user.

Some examples of service concepts

- Climate statistics for road winter maintenance for municipalities to assess work of the contractors

- Consultation on wind power: step 1) wind atlas (modelled) for wind power potential (tailored for the wind power production). Step 2) site studies for wind power plat (tailored for the specific client)

- Authoritative statements for insurance compensations – complex cases can be considered as a small research and experts' role in these studies are important.

Some examples of one time tailored services:

- Climate risks assessments in the present climate. Historical climate and sectoral data are needed to determine potential critical threshold values or to model relationships between the sectoral and climate data.

- test reference year data for construction

These may require a research project or specific consultation service with adequate uncertainty estimate. When considering scientific publications, *normal peer review –process and scientific debate acts as quality assurance*. In the consultation climate services without scientific practices and quality assurance should be taken care in other ways. *Currently there is no information on quality assurance of consultation companies providing climate services.*

ANNEX 6: INTRODUCED UNCERTAINTY WHEN HARMONIZING RESOLUTIONS OF CLIMATE DATA AND NON-CLIMATE DATA

A. Climate information

Operational settings in regional adaptation planning often entail the post-processing of climate information as originally provided by climate scientists. Such post-processing may include spatial rescaling, segmenting or merging, and rotating the original dataset. The main reason for this is the fact that the geographic, architectural, or other information systems (for instance, GIS and CAD software) have been used for a long time by local and regional governments to store digital representations of the technical infrastructure, building stock, and socioeconomic capital of urbanities, metropolitan areas, or larger regional units in formats and scales appropriate for various levels of integrated analysis. On the other hand, the need to include climate change forecasts in a comprehensive manner is relatively recent and information provided by the climate community is often converted to match pre-existing databases instead of the other way around. Post-processed climate information may or may not be stored permanently as a stand-alone dataset, depending on the analytical workflow and the plentiful of alternative ways in which spatial analysis or representation can be achieved. However, in all workflows, when climate information is interacting with, merged, or overlaid to other spatial information, its spatial representation is modified. A second reason is that the geographical unit at which adaptation-relevant socioeconomic processes take place and makes sense to analyze is often different than units used in weather and climate research, which also motivates post-processing.

In this exercise we use a case from a recently completed EU FP7 project to explore the scale of error that is introduced to climate information by post-processing. The original climate forecasts were provided at a 0.5-degree grid, which was afterwards downscaled and rotated to a 25 × 25 km grid in order to be combined with population and macroeconomic forecasts. The analysis first selected three sampling areas in the original grid of approximately 1000 × 1000 km wide and compared the distribution of values of the original climate dataset to that in the downscaled dataset (Fig. A1).

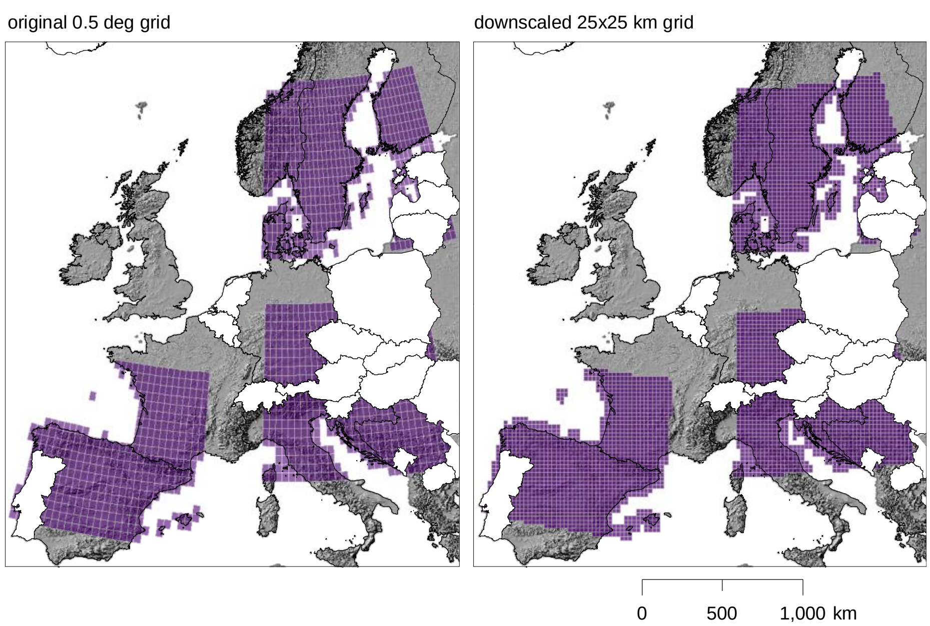

FIGURE A-1 ORIGINAL (LEFT) AND POST-PROCESSED (RIGHT) GRID OF CLIMATE INFORMATION FOR THREE SAMPLING AREAS

The comparisons were repeated for a Europe-wide random sample of points (see Fig. 4) and for population density (see Section B). The introduced uncertainty was explored by using the decadal mean value of precipitation and temperature in 2031-40 under scenario RCP 4.5 for the three sampling areas shown in Fig. A1. The following descriptors of the distribution were derived: minimum, maximum, median, mean, standard deviation, and probability density plots.

Assuming that the original climate dataset is the error-free point of reference, the scale of introduced error in the post-processed samples ranges from 0 to 6.5 % for the minimum and maximum values, mean, median, and standard deviation. An exception is the minimum value of temperature for specific regions, where the range is 28 to 63.6% (see Table A1). Differences in the probability density functions are generally higher for temperature, but the distribution is not changed significantly (see Fig. A2 and Fig. A3) except of the smoothing of values characteristic of the particular downscaling method employed in this case (spatially weighted averaging).

TABLE A-1 SAMPLE AND SUBSAMPLE DIFFERENCES IN THE DISTRIBUTION OF PRECIPITATION AND TEMPERATURE

		Sample			***SW Europe***			***N Europe***			***Central Europe***		
		orig.	**dnsc.**	**|%Δ|**	**orig.**	**dnsc.**	**|%Δ|**	**orig.**	**dnsc.**	**|%Δ|**	**orig.**	**dnsc.**	**|%Δ|**
Precipitation	min	24.7	25.6	3.6	24.7	25.6	3.6	40.8	40.8	0.0	37.2	37.22	0.1
(mm)	max	178.3	178.1	0.1	125.7	125.0	0.6	131.5	129.9	1.2	178.3	178.1	0.1
	median	58.0	58.1	0.2	55.1	54.5	1.1	58.9	58.9	0.0	57.6	58.9	2.3
	mean	61.5	61.3	0.3	55.1	55.1	0.0	62.1	61.1	1.6	65.0	66.0	1.5
	std. dev.	20.1	19.9	1.0	19.4	19.3	0.5	14.5	12.5	13.8	24.4	23.9	2.0
Temperature	min	-1.1	-0.5	54.5	6.3	6.3	0.0	-1.1	-0.4	63.6	-0.7	-0.5	28.6
(ºC)	max	19.1	19.1	0.0	19.1	19.1	0.0	9.7	9.6	1.0	16.8	16.8	0.0
	median	9.3	9.7	4.3	13.7	13.9	1.5	6.2	6.6	6.5	10.0	10.1	1.0
	mean	9.4	10.0	6.4	13.9	14.0	0.7	5.7	6.0	5.3	10.3	10.4	1.0
	std. dev.	4.1	4.0	2.4	2.4	2.3	4.2	2.3	2.2	4.3	2.7	2.7	0.0

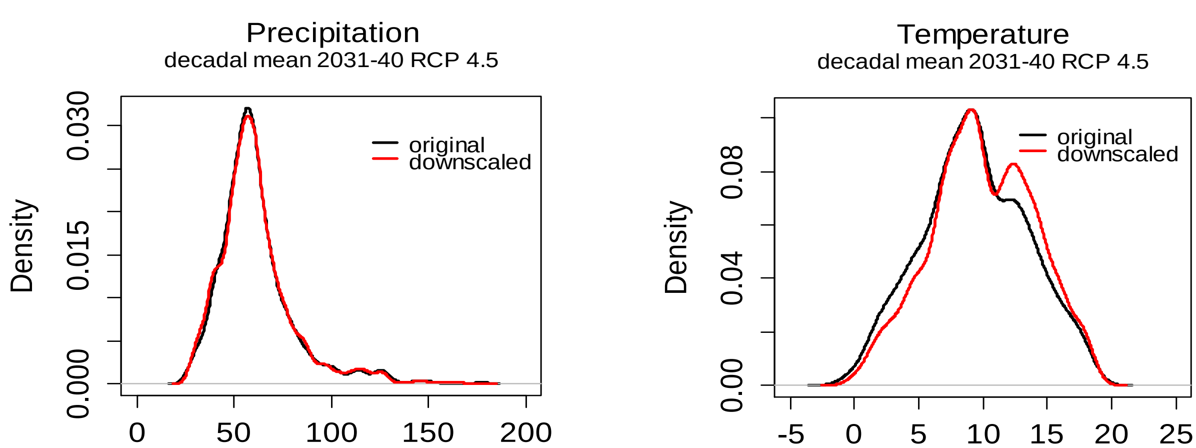

FIGURE A-2 SAMPLE DIFFERENCES IN THE DENSITY DISTRIBUTION OF PRECIPIATION (L) AND TEMPERATURE (R)

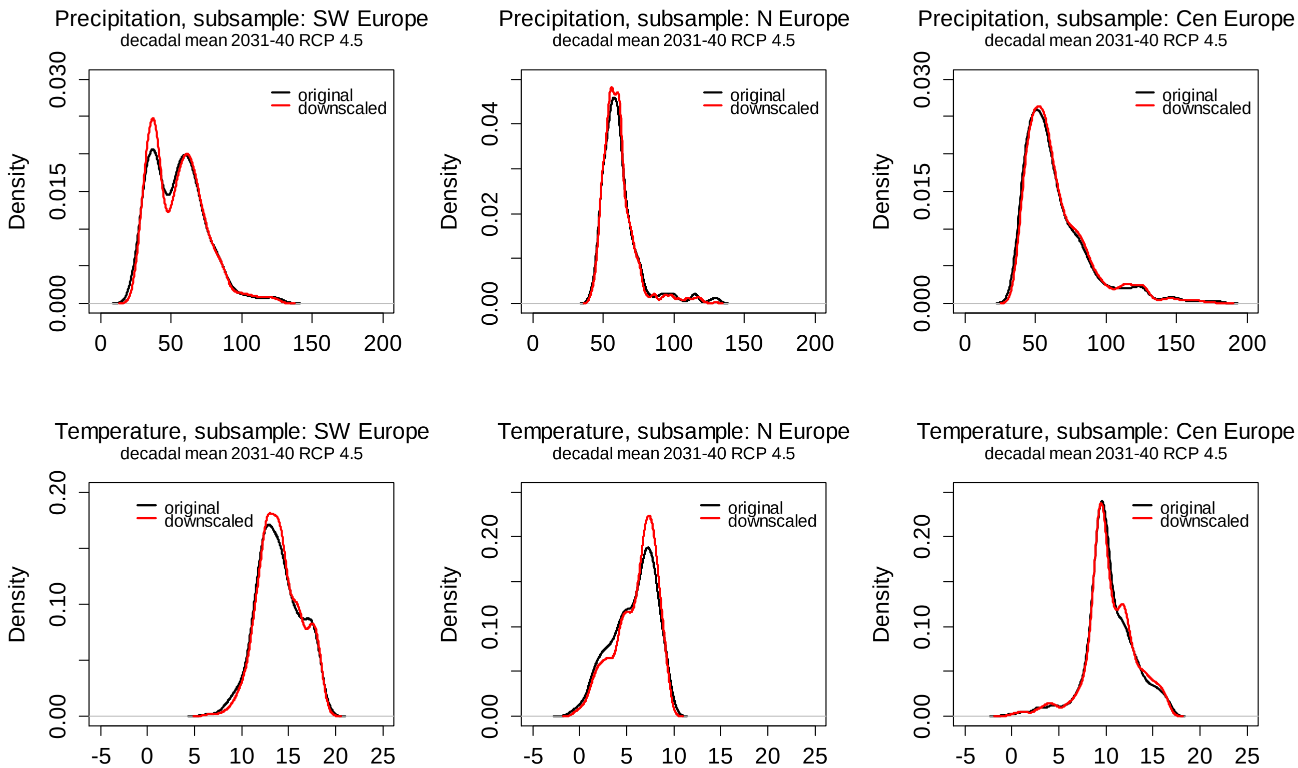

FIGURE A-3 SUB-SAMPLE DIFFERENCES IN THE DENSITY DISTRIBUTION OF PRECIPITATION (TOP) AND TEMPERATURE (BOTTOM)

The above evaluations were repeated for a random point sample across the European continent (Fig. A4). Again assuming that the original climate dataset is the error-free point of reference, the introduced error in the downscaled dataset ranges between 0 and 12.2% (0 to 6.8 excluding the minimum values) (see Table 2). The probability density distributions do not differ substantially, although as before they reflect the smoothing of variation introduced by the downscaling methodology (see Fig. A5).

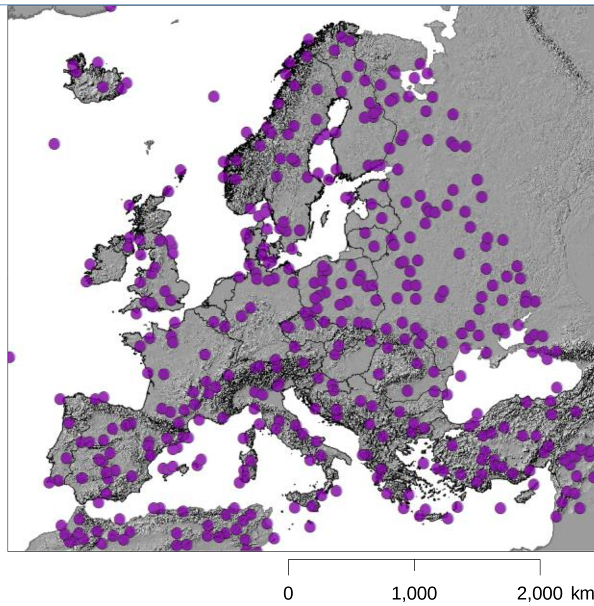

FIGURE A-4 ALATERNATIVE SAMPLING METHOD WITH RANDOMLY GENERATED COORDINATE POINTS

TABLE A-2 RANDOM SAMPLE DIFFERENCES IN THE DISTRIBUTIONS OF PRECIPITATION AND TEMPERATURE

		orig.	dnsc.	|%Δ|
Precipitation	min	9.0	8.0	11.1
(mm)	max	170.9	182.6	6.8
	median	51.1	51.0	0.2
	mean	55.1	55.5	0.7
	std. dev.	25.4	26.1	2.8
Temperature	min	-4.9	-5.5	12.2
(°C)	max	22.8	22.5	1.3
	median	10.1	10.1	0.0
	mean	10.8	10.8	0.0
	std. dev.	5.2	5.1	1.9

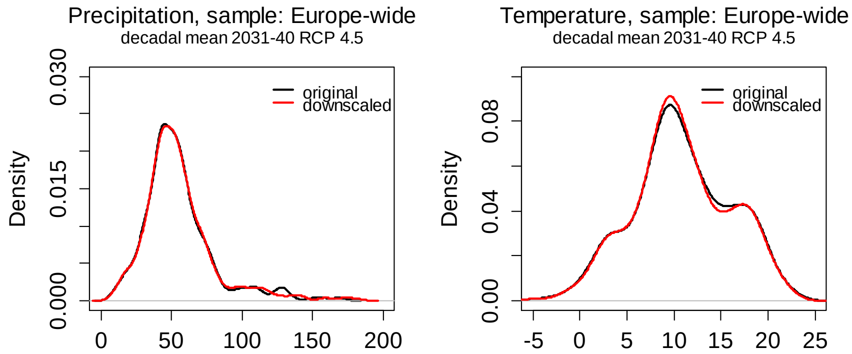

FIGURE A-5 RANDOM SAMPLE DIFFERENCES IN THE DENSITY DISTRIBUTION OF PRECIPIATION (L) AND TEMPERATURE (R)

Overall, the above simple comparison exercises suggest that the scale of error is about 10% in the median, mean, and standard deviation of the distributions. The exception is location-specific extreme values: European-wide it does not exceed 12%, but in location-specific, variable-specific, and tail-specific cases, the error may be substantially higher (29–64% for minimum temperature). In addition, the impact of post-processing methodology can be detectable; for instance, the probability density distributions show the geographical smoothing of the underlying spatially weighted averaging downscaling method (note that advanced downscaling methods have been developed by climate scientists that can entail smaller errors).

B. Population

An evaluation similar to that in Section A was performed for gridded population data. The variable used is population density for evaluating the scale of error, whereas the natural logarithm (denoted as log) of population density is used for evaluating the distributions of population density. The difference in this case is that the original population data came at a 1-km grid by EUROSTAT/GEOSTAT and were thus up-scaled to the custom 25 by 25 km grid, as opposed to the climate data that were downscaled from their original resolution. Fig. A6 displays the original and post-processed population information.

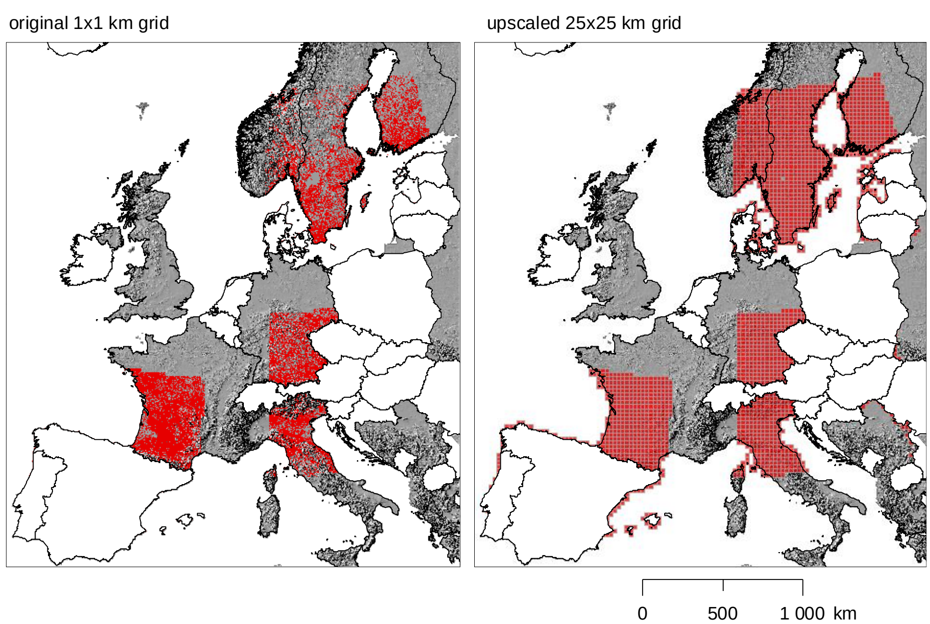

FIGURE A-6 ORIGINAL (L) AND POST-PROCESSED (R) GRID OF POPULATION FOR 3 SAMPLING AREAS

The comparisons in Table A3 show an average error of 70% in population density. The main source for this error is in maximum and mean population densities ("max", "mean") and standard deviations of densities ("std. dev."). This translates to a reduced ability of the coarser (up-scaled) grid of 25 km² to capture the geographical variation in population that is contained in the original 1 km² grid. More specifically, the post-processing operation has eliminated high concentrations of population in relatively confined geographical limits – this means that *cities* are effectively erased. Figures A7 and A8 confirm this feature – notice especially the right-hand graph of Fig. A8 ("Cen Europe") that shows that in densely populated areas the post-processing significantly smoothens the occurrence of high population densities.

TABLE A-3 SAMPLE AND SUBSAMPLE DIFFERENCES IN THE DISTRIBUTION OF POPULATION DENSITY

	Sample			*SW Europe*			*N Europe*			*Central Europe*		
	orig.	upsc.	|%Δ|	orig.	upsc.	|%Δ|	orig.	upsc.	|%Δ|	orig.	upsc.	|%Δ|
min	1	0	100	1	0	100	1	0	100	1	0	100
max	52898	5206	90	52898	5206	90	24546	1874	92	27844	3482	87
median	26	30	15	23	24	4	11	9	18	65	89	37
mean	209	81	61	198	74	63	92	31	66	306	139	55
std. dev.	905	193	79	1225	240	80	462	100	78	864	202	77

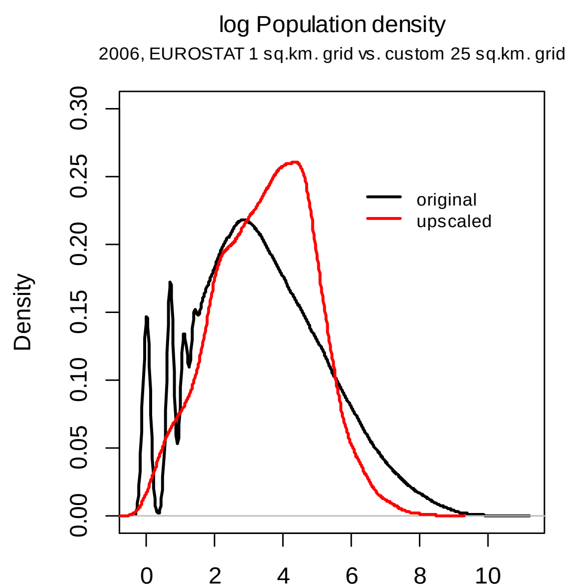

FIGURE A-7 SAMPLE DIFFERENCES IN THE DENSITY DISTRIBUTION OF LOG POPULATION DENSITY

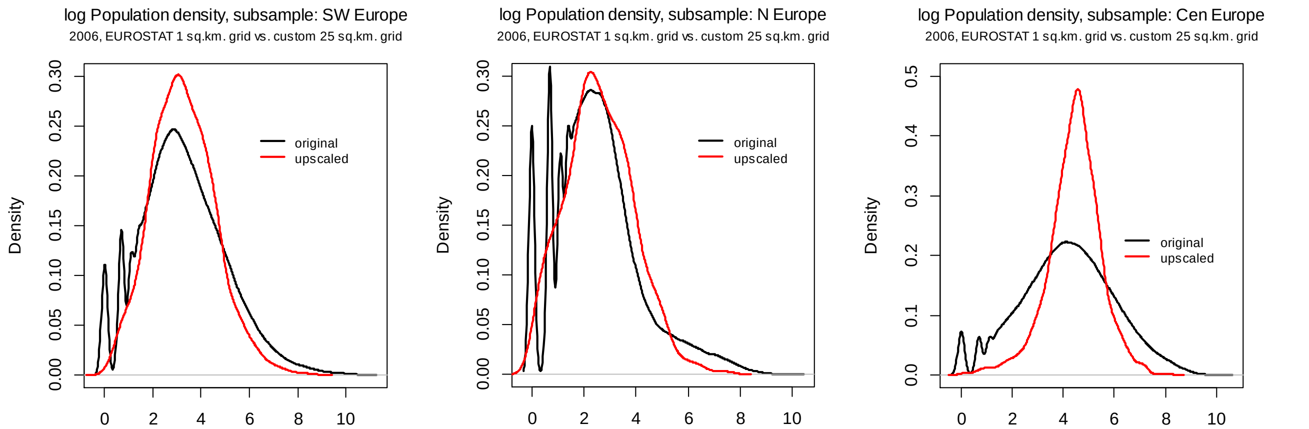

FIGURE A-8 SUBSAMPLE DIFFERENCES IN THE DENSITY FUNCTION OF LOG POPULATION DENSITY

The above misrepresentation is ameliorated when the unit of analysis is larger regional administrative units. In particular, the preceding density comparisons were repeated by using population density per NUTS-3 area sourced from the original 1 km^2 and up-scaled 25 km^2 population grids.

In this case the comparisons yielded an average error of 23%, which is approximately one-third smaller than in the case of grid cells, with reduced differences in maximum and mean values and standard deviation (see Table 4), as well as greater preservation of detail in the density distribution (see Figs. A9 and A10). While the ameliorations of the error can resolve European-wide or large regional analysis error issues, the problems remain for individual NUTS-3 regions. Figure A11 shows the errors per individual NUTS-3 region in the sample, indicating that when focusing on particular geographies, while the absolute errors in many regions is contained in the 0-10% range, they exceed the 50-100% in many others.

One source of this error—namely not in multi-region statistics, but in locality-specific statistics—is misrepresentation of the meaningful geographical unit of analysis, including human-made borders. As seen above, population densities are affected by up-scaling the unit of analysis and effectively erasing the concentration of activity in cities. Absolute population counts may ameliorate this problem, but will suffer from the same smoothing of the spatial heterogeneity of socioeconomic activity.

TABLE A-4 SAMPLE AND SUBSAMPLE DIFFERENCES IN THE DISTRIBUTION OF POPULATION DENSITY

	Sample			*SW Europe*			*N Europe*			*Central Europe*		
	orig.	upsc.	|%Δ|	orig.	upsc.	|%Δ|	orig.	upsc.	|%Δ|	orig.	upsc.	|%Δ|
min	0	7	0	9	9	0	7	7	0	0	7	0
max	4018	2244	44	1557	1128	28	3459	1685	51	4018	2244	44
median	111	117	5	58	57	2	37	36	3	135	144	7
mean	274	183	33	123	106	14	195	126	35	328	236	28
std. dev.	515	243	53	201	159	21	567	312	45	553	243	56

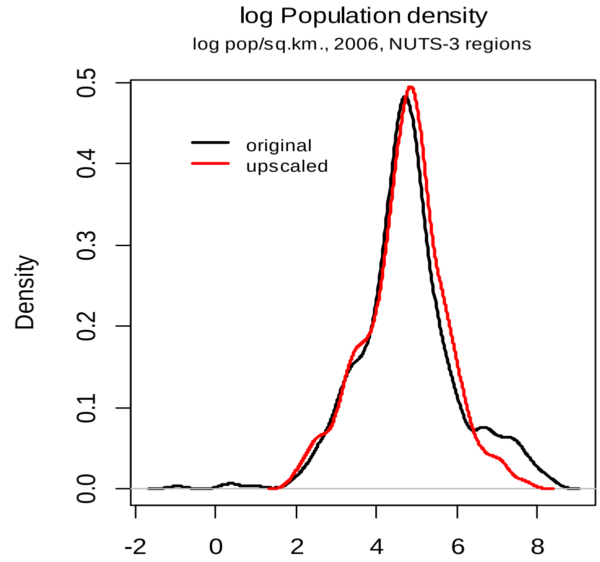

FIGURE A-9 SAMPLE DIFFERENCES IN THE DENSITY DISTRIBUTION OF LOG POPULATION DENSITY

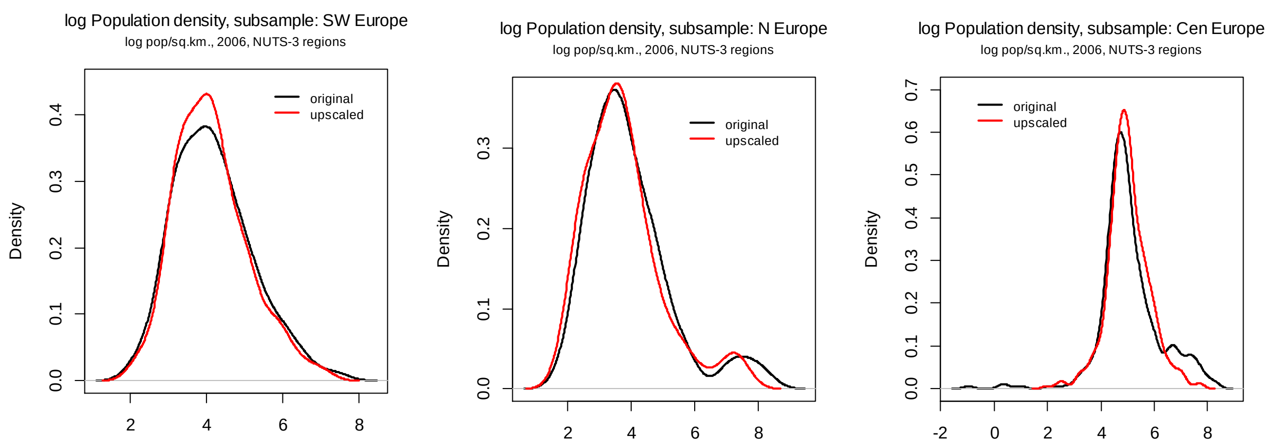

FIGURE A-10 SUBSAMPLE DIFFERENCES IN THE DENSITY DISTRIBUTION OF LOG POPULATION DENSITY

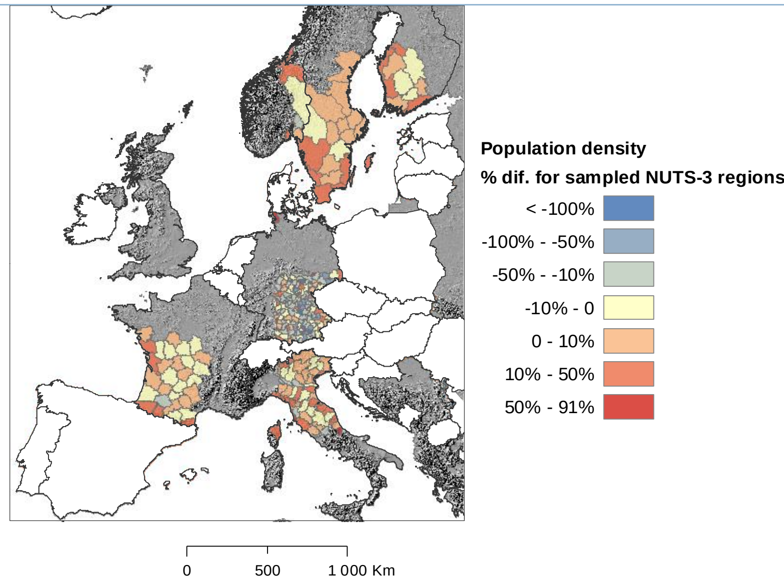

FIGURE A-11 STANDARDIZED COMPARISON OF DEVIATIONS AT NUTS-3 LEVEL

C. Conclusion

As far as post-processing errors are concerned, the above comparisons show that there are two distinct aspects in combining climate and socioeconomic data:

- Climate data may be less sensitive to post-processing alteration compared to socioeconomic data.
- The chosen geographical unit of analysis is a defining factor in the amount of error.

Note, however, that in this comparison exercise climate information was downscaled whereas population information was up-scaled using a scale-sensitive variable; whether a downscaling of population information or use of scale-insensitive variables would have introduced smaller errors remains to be seen. Nevertheless, it appears plausible to argue for a better *conceptualization* of the geographical unit of analysis. This does not pertain just to the size of grid cells or administrative units. The main problem is rather the sensible representation of clusters of human activities in space: when resolutions exceed a few hundred meters or one kilometre, a neatly organized gridded representation of the world may be inappropriate altogether (i.e. the problem of zones versus grid cells).

ANNEX 7. CASE STUDY: HOW LEGISLATIVE FRAMEWORKS STIPULATE THE USAGE OF 'BEST' CLIMATE INFORMATION

Introduction

Planning for climate change adaptation and the implementation of corresponding measures calls for a strategic approach. The European Commission prepared an adaptation framework for Europe to ensure coherence in adaptation actions across sectors and levels of governance (EC, 2013). At the country level, national adaptation strategies and plans provide a general and mostly non-binding policy framework to guide adaptation activities of government authorities and non-state actors.

While national adaptation strategies and policies aim to promote adaptation action, they can also slow down the progress. This includes for example guidance and consistency from higher-level governments, restrictive policies, shifting political ideologies and a lack of regulation and/or funding (Baker et al. 2012, Groth and Nuzum 2016, Porter et al. 2015, Weyrich 2016). Beside these external factors, there are also other reasons for this slowdown that are related to the internal processes of institutions. These include a lack of technical data, unfamiliarity with such data, unclear or ill-defined responsibilities, competing priorities and lack of expertise (Baker et al. 2012, Groth and Nuzum 2016, Measham et al. 2011).

Taking informed decisions concerning adaptation to climate change and assessing the risks involved depend on the appropriate production and use of climate information. The quality of the delivery of climate information can be measured in the usability of provided information. Usability is defined 'by [the] users' perception of what knowledge can be readily applied to their decision' (Lemos and Rood, 2010). This concept allows for the theory that climate information produced by scientists and considered as the 'right' information may do not survive in the transition space before it reaches the user. Lemos et al. (2012) termed this a 'climate information usability gap'. The author team clearly distinguishes between useful information (as provided by producers of climate information) and usable information (as required by users of climate information).

Legal institutions and instruments play an important role in climate change adaptation (Cortekar and Groth, 2015). Law can facilitate adaptation, using regulation to reduce exposure or sensitivity to climate hazards, establishing the legal architecture for new market mechanisms, and funding arrangements for adaptation costs and liability for climate impacts (McDonald, 2011).

Adaptation planning can be determined on different scales of institutional context. Adaptation actions can be anchored at the national level or on a sub-level, i.e. the states level. For comparison we have chosen two countries that are considered to be European leaders in adaptation planning (Lorenz et al., 2016): The UK where the national government has the key role in setting the agenda, and Germany where this happens at the state level (Länder).

Here we explore the differences in the integration and choice of climate information in adaptation actions for spatial planning in Germany and the UK and how these are impacted by the legal and regulatory frameworks of the two countries.

Stipulations for usage of climate data: legislation towards adaptation

Germany: national legislation towards adaptation

To cope with the climate change conditions efficiently, the German federal government has adopted the Strategy for Adaptation to Climate Change (DAS) in 2008 (Die Bundesregierung, 2008) and Adaptation Action Plans (APA) (Die Bundesregierung, 2011). The DAS strategy highlights areas likely to be affected by climate change or already showing evidence of impacts, as well as basic options for a possible approach and the requirements for action in various sectors. This provides the overarching framework and guidance for adapting to the impacts of climate change, and forms the starting point for all political efforts to adapt to climate change. A first evaluation and progress report about this framework was published in 2015 (Umweltbundesamt, 2015).

"Mainstreaming" climate adaptation in legal approaches is necessary to facilitate climate change adaptation. A recent study (Bubeck et al., 2016) has scanned and analysed the German legal framework to find out where climate adaptation is required by law. Between 2008 and 2013 amendments of three federal laws introduced 'climate adaptation'. The most frequent reference to this can be found in the Federal Building Code (Baugesetzbuch, BauGB), which addresses the issue of climate adaptation in general as well as for urban planning legislation in particular. The Federal Water Act (Wasserhaushaltsgesetz, WHG) also points to the effects of climate adaptation. In the Federal Regional Planning Act (Raumordnungsgesetz, ROG) climate adaptation is explicitly addressed in a regulation. Planning regulations, for example, are very hierarchical in Germany as regional and local planning is supposed to fit in higher-level (i.e. national) plans. A list of the statutory provisions can be found in Bubeck et al. (2016), see table 1.

The German federal states ('Bundesländer') play key in roles in delivering and implementing adaptation solutions. They can set up their own 'Bundesländer'-specifc adaptation acts and set out roadmaps for action on climate change. Recent studies (Bubeck et al., 2016; Lorenz et al., 2016) showed that these are considered a political declaration with 'advisory character' due to the lack of clear targets on adaptation, responsibilities, and sanctions in the law. Whilst mitigation targets are set out clearly, the articles on adaptation leave the extent of expected action on adaptation vague and unclear. As a result, there is a lack of top-down guidance for progressing through the stages of local adaptation planning compared to the UK (see below).

The United Kingdom (UK): national legislation towards adaptation

The approach to climate change adaptation in the UK is somewhat different compared to Germany. In the UK, the national government plays a key role in agenda setting and coordination (Lorenz et al., 2016). Since 2008 the Climate Change Act provides a legally binding framework for building the UK's ability to adapt to the changing climate. On a five-yearly cycle, the Act requires the Government to compile an assessment of the risks for the UK arising from climate change. Building on that the Government needs to develop an adaptation programme to address those risks and establish resilience to climate change on the ground. In accordance with the requirements of the Act, the UK Government just published the second assessment of the risks and opportunities (UK 2017), which follows on from the first report published in 2012. This report builds on the UK Climate Projections (UKCP09, see http://ukclimateprojections.metoffice.gov.uk/). The UK Climate Projections are nationally funded and the principal source for UK climate information (both climate projections and observed past climate data).

The regulatory and planning framework underwent substantial changes between 2010 and 2015 because of the decentralization and localism agenda of a new coalition government. The new national planning still requires adaptation actions from Local Governments but the detailed guidance and national planning has been withdrawn. In addition, these regulation changes came along with a major cut of their budget (Porter et al., 2015).

Comparison of the German and UK legislation

The approaches to adaptation are somewhat different in the two countries. Despite some national differences in governance structures, planning law plays a key role in both countries and Local Government is a key implementer of adaptation. Figure 1 gives a comparison of the legal and policy context of the two countries based on the example of adaptation planning.

Figure 1: Source: Lorenz et al., (2016). The approaches to adaptation are somewhat different in the UK and Germany. The overview demonstrates this for legal and policy context of local adaptation planning. In the UK, the national government plays a key role in agenda setting and coordination. In Germany, the

states (Länder) play key roles in setting priorities and developing regulatory frameworks whilst national government is the provider of scientific information and financial support (Massey 2015).

Integration of climate information

Germany: access and usage of climate information

One third of the cities in Germany have an adaptation plan (Reckien et al 2014) and one third of the regional planning authorities consider climate adaptation in regional plans (Overbeck et al 2009). A recent study focussing only on one state of Germany found that about two thirds of the municipalities engage in activities related to climate change adaptation. So the topic adaptation is still considered as new but one of increasing importance (Hackenbruch et al., 2017).

The usage of climate parameters is often limited to observed past and current climate data. The climate data municipalities use consist primarily of measurements and urban climate analyses, which in most cases refer exclusively to the current climate. Municipalities use analyses of the current climate and documents such as climate function maps (maps that are based on factors affecting the climate, e.g. land use, topography and represent thermal and dynamic microclimate) or planning recommendation maps more often than climate projections (Hackenbruch et al., 2017; Lorenz et al., 2016).

The trigger for specific adaptation actions currently relies on 'subjective' event thresholds (Hackenbruch et al., 2017). If climate change is considered in planning, it is often based on general knowledge about climate, e.g. increase in global temperature, but the knowledge about the local changes is limited. Often experiences of past events alone have formed the basis for climate adaptation plans (Hackenbruch et al., 2017).

Most municipalities (Hackenbruch et al., 2017) take and use climate information offered by higher authorities on the state or federal level but rarely consider information offered by scientific institutions, including the IPCC, or climate services. Hackenbruch et al. (2017) revealed that most Local Governments seem to be unaware of freely available, reliable climate information sources (e.g. regional climate information from EURO-CORDEX).

Uncertainty and climate projections' lack of skill have been frequently used to justify policy paralysis and inaction (Lemos and Rood, 2010). Thus the strongly regulated German planning system favours the use of past and present instead of future climate data. Spatial planning recommendations have to be based on data that are spatially sufficiently concrete and accurate so that valid planning recommendations can be made (BMVBS 2013). This is something climate projections struggle to help with due to their inherent uncertainty. Not using climate projections is therefore less an issue of insufficient technical capacity or lack of tools but more an issue of lack of fit with regulatory and institutional requirements in the planning system (Lorenz et al., 2016). One of the consequences is that local governments are often afraid to take actions that are not prescribed by law because they run the risk of being sued. As an example when publishing a risk map for heavy rain impacts, property owners can take legal actions due to the depreciation of property value (Bubeck et al., 2016).

A number of research projects (e.g. "KlimREG" or "KlimaMORO", http://klimamoro.de/) have been launched to improve the knowledge transfer between science and Local Goverments to develop methods for creating a climate change suitable regional plan together. During the life span of the project, the regions benefited from the advice by the research assistance as well as from the mutual exchange. Good practices of this exchange have recently been published in a guideline book for climate-change suitable regional planning (BMVI 2017). One of the recommendations calls for the integration of climate protections in the field of action for regional planning.

UK: access and usage of climate information

Local governments are better-informed and more confident about accessing and using the 'right' kind of climate information than a decade ago (Porter et al., 2015). A decade ago, local authority staff struggled to find scientific information that they could understand, and they lacked much in the way of a planning framework in which they could use climate science to identify risks or prioritize measures for dealing with them (Demeritt and Langdon, 2004). There was clear evidence in the UK for what Lemos et al. (2012) termed the 'climate information usability gap'. In response, the UK Government invested in new, more policy-focused adaptation science, such as new finer resolution and uncertainty explicit climate projections (UKCP09, http://ukclimateprojections.metoffice.gov.uk/) and a national risk assessment (CCRA), as well as in knowledge brokerage including UKCIP, the Environment Agency's Climate Ready Programme, to deliver climate science that is more accessible to, and understandable by Local Governments. Porter et al. (2015) underpinned the success of this action with their survey showing that there is now near universal (91.5%) awareness of the latest UKCP09 projections.

The UK adaptation progress has largely been forced through the central government by a top-down push. From 2008-2010 local authorities had to report against a process-based framework to help their preparations for a changing climate. In 2010, this central performance monitoring was ended. Due to the novelty of the adaptation agenda and the lack of knowledge, it is questionable if the local authorities would have used climate projections to the same extent as they did had without this top-down push (Lorenz et al., 2016).

Since 2010, a change in the coalition government has introduced substantial changes to the regulatory and planning framework. Due to the changes, adaptation actions have been marginalized (Porter et al., 2015).

However, there are still barriers to unleash/take advantage of the full potential of climate projection data for implementing adaptation plans. Cognitive challenges remain in the form of the complexity, uncertainty, and resolution of climate information (Porter et al., 2015). The use of climate projections remains confined to awareness raising in the early stages of adaptation planning, rather than becoming integrated throughout the process (Lorenz et al., 2016).

Conclusion

Regulatory and legal context are key determinants of the kind and quality of climate information used by the implementers of adaptation actions. In Germany and the UK, the use of climate projections has not been successfully integrated into local strategic and adaptation planning. In the UK, the local governments are aware of the 'best' available climate information but they only use this information in the early process of planning for awareness rising rather than integrating the information throughout the process. German Local Governments make substantial use of past and present climate data. The current regulatory framework requires the use of concrete and accurate information and hence prevents the use of climate projections due to their inherent uncertainty (Lorenz et al., 2013). In addition, as the use of climate projections is not a mandatory requirement for receiving national funding for adaptation, it is difficult to justify any allocation of resources to increase their use (Bubeck et al., 2016; Lorenz et al., 2016).

There is little demand for climate projections in local adaptation planning in either country (Bubeck et al., 2016; Lorenz et al., 2016; Porter et al., 2015). The lack of specific adaptation planning results in little decision-making or actions taken that would require the use of climate information. Local government in England has not only experienced a decline in use of climate projections, but also the waning of the climate change adaptation agenda more widely, amidst changes in the planning and regulatory framework and severe budget cuts.

Hackenbruch et al. (2017) aimed to identify the specific needs of municipalities related to climate parameters of climate projection data. This was hindered because many survey participants indicated not to be familiar with dealing with climate projection data or climate parameters.

The investigation of the UK Government in more policy-focused adaptation science, such as new finer resolution and uncertainty explicit climate projections have led to largely overcome the informational access and cognitive understanding barriers (UKCP09, work on UKCP18 is underway, with products becoming available over the next two years, see for more information http://ukclimateprojections.metoffice.gov.uk).

In Germany, a similar national coordinated effort (ReKliEs-De, http://reklies.hlnug.de) has started to analyse and to complement a new set of climate projections for Germany. The overall goal of ReKliEs-De is to derive robust climate change information on high spatial resolution (12.5 km x 12.5 km ReKliEs-De-grid, which corresponds to the EURO-CORDEX grid) for Germany. The pilot project of spatial planning "KlimaMORO" (http://klimamoro.de) that developed adaptation strategies to climate change between 2009 and 2014 for pilot regions in Germany has an expert group working on 'data and standards' testing how the usage of climate projections can be promoted in spatial planning.

Addressing the question of usability is not just about better understanding the interplay between what science or climate services can provide and what local governments need or want, but also about what users can actually do within the political and economic constraints. Beside these constraints also cultural and civic factors need to be considered. The comparative analysis by Skelton et al., 2017 reveals that national climate scenarios are strongly influenced by the civic epistemology of each country, which defines who has a say, what roles scientists and users should play and how the two interact. The author team concludes that several future discussions are needed to better understand the different cultures for producing climate information.

To the extent possible, adaptation law and policy should be based on the best available science and climate information. However, law is not known for its swift response to new information and legal reforms often lag well-behind rapidly remerging science (Bubeck et al., 2016; McDonald, 2011).

ANNEX 8 - VALUE CHAIN IN CLIMATE SERVICES

The value chain for climate services is usually more complex than for weather services, yet in essence the logic of value propagation remains the same (Fig. B 1 and B 2). The monetizable value is downstream higher than upstream, even though the upstream part is indispensable to produce downstream services. As the market develops more product differentiation will occur and hence more value chains (alternative pathways to generate CS) will emerge, probably with a rising share of input of non-climate data and knowledge.

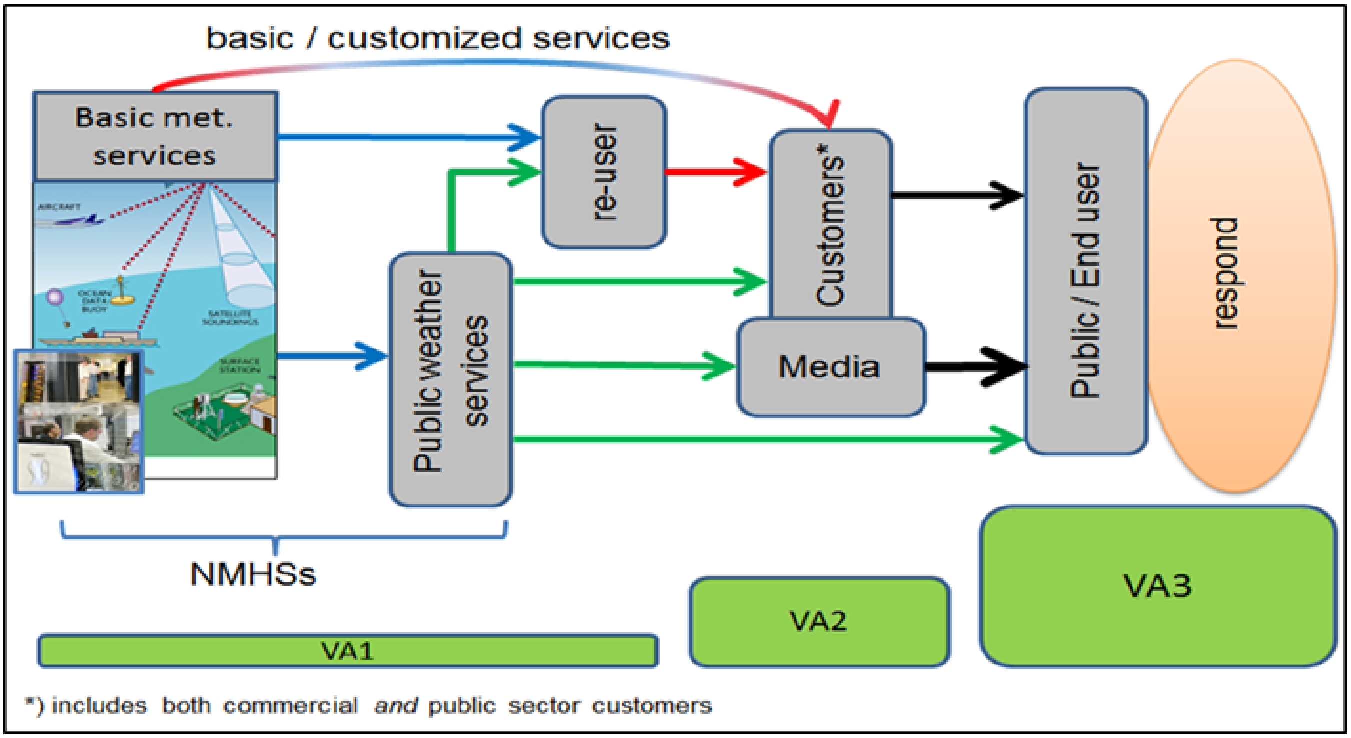

FIGURE B-1 OUTLINE OF TYPICAL VALUE CHAIN OPTIONS IN WEATHER AND CLIMATE SERVICE GENERATION (SOURCE: PERRELS ET AL 2013)

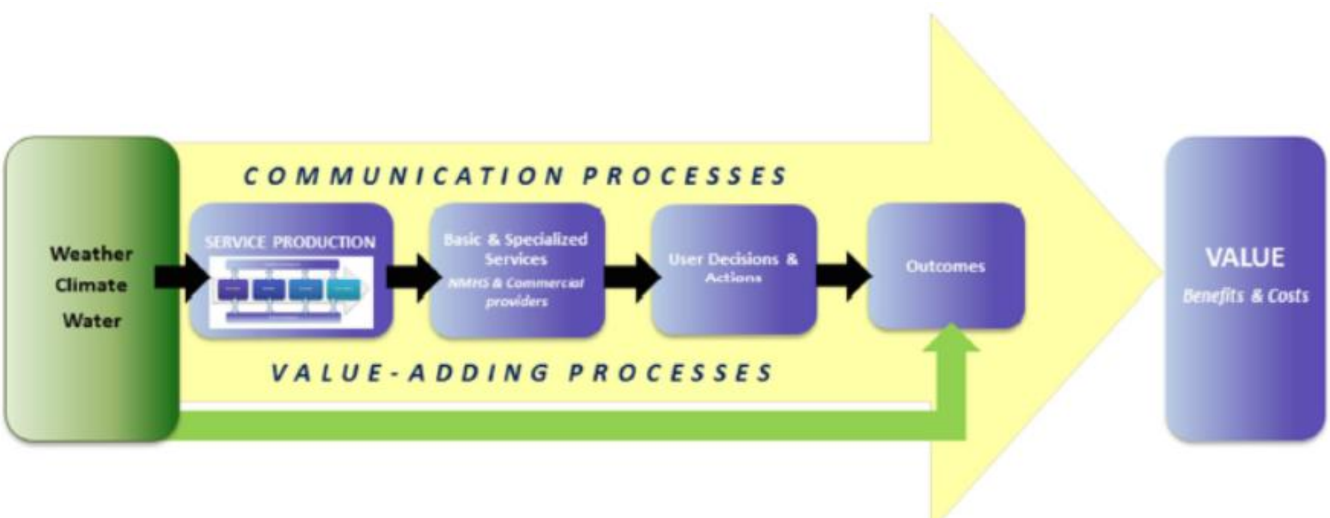

FIGURE B-2 KEY BUILDING BLOCKS IN VALUE CHAIN FOR WEATHER & CLIMATE SERVICES (SOURCE: ANDERSON ET AL 2015)

The above examples for weather and climate services are applications from a general concept of how services can be generated on the basis of public (basic) data, especially when these data are opened for use and subsequent service development to third parties in the public and private sector, against no or minimal charges (fig. B-3).

Open data value chain

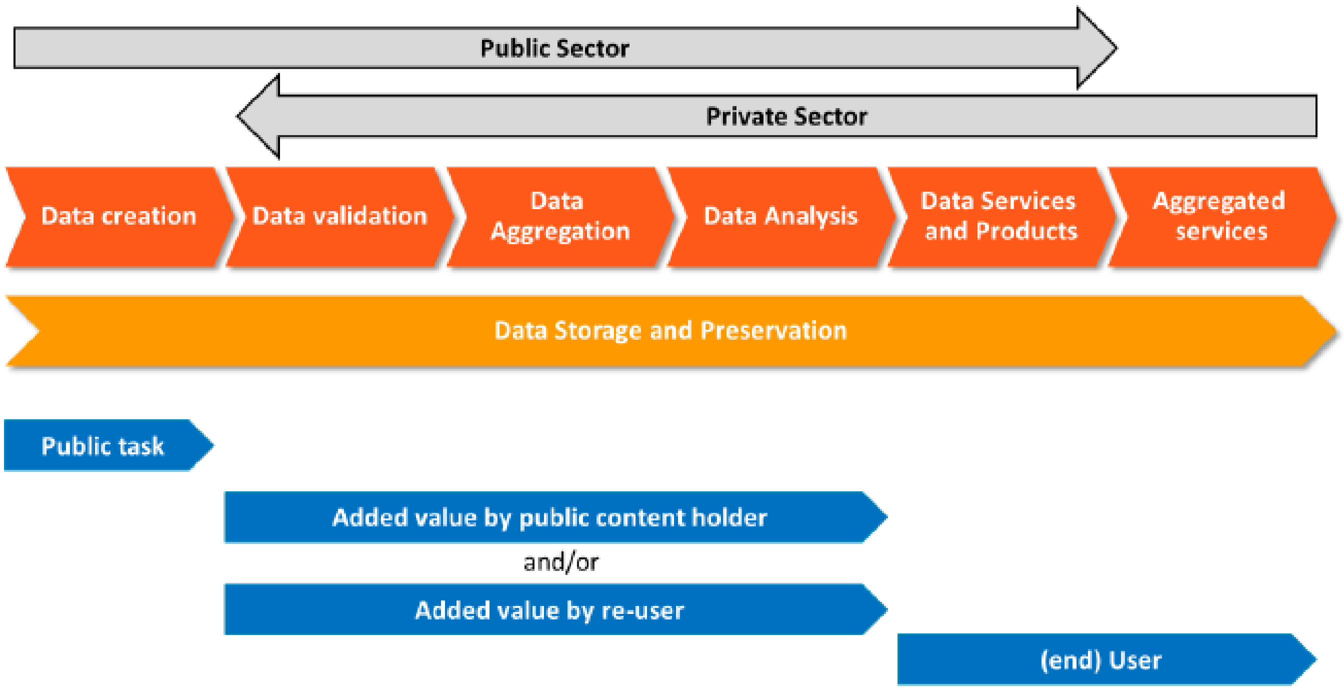

FIGURE B-3 OPEN DATA BASED SERVICE GENERATION (SOURCE: EUROPEAN UNION 2017)

In principle it is possible to assess constituent elements of the value chain and how they interact and thereby produce estimates of value propagation potentials and degradation effects by segment of the value chain. Eventually it enables to attribute approximate quantifications of the effects of imperfections per segment, whereas at the same time it helps to identify remedial actions per segment. FMI has been applying Weather Service Chain Analysis (WSCA; fig. B-4) to various weather service segments (Nurmi et al 2013; Pilli-Sihvola et al 2016). During the EU-MACS project a Climate Service Chain Analysis (CSCA) will be explored as elaboration of WSCA.

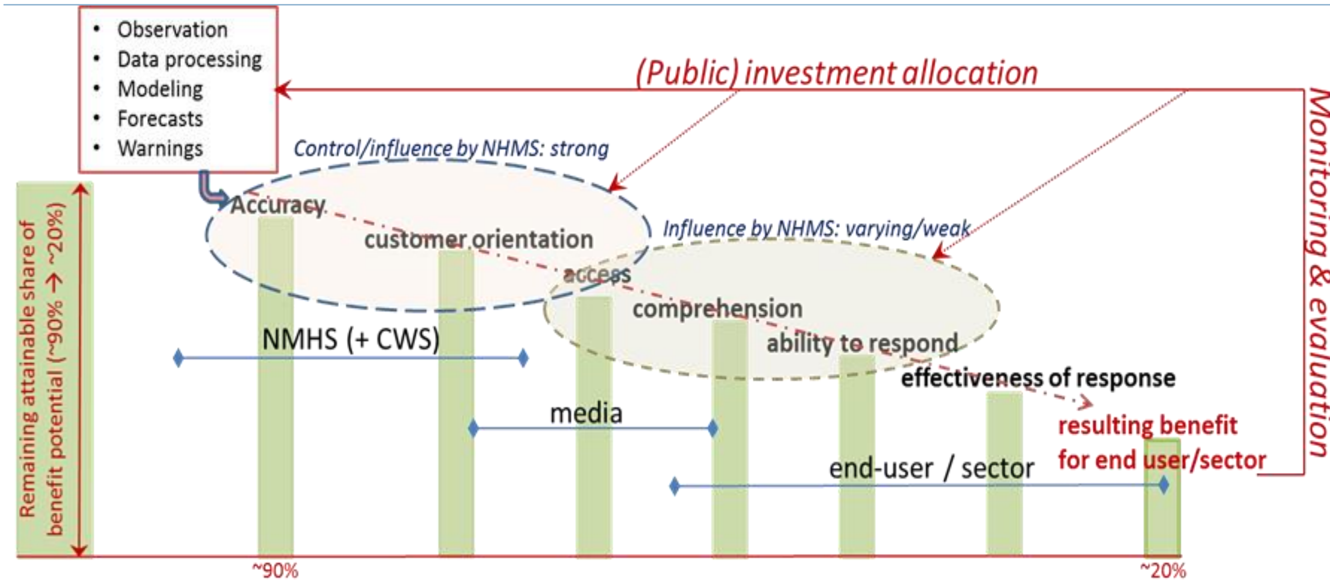

FIGURE B-4 INFORMATION DECAY PROCESS IN SERVICE DELIVERY BY VALUE CHAIN SEGMENT (WSCA) (SOURCE: PERRELS ET AL 2013)