ANALYSIS OF EXISTING DATA INFRASTRUCTURE FOR CLIMATE SERVICES

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List of Abbreviations

ADAGUC	Atmospheric Data Access for the Geospatial User Community
BADC	British Atmospheric Data Centre
BSC	Barcelona Supercomputing Centre
C3S	Copernicus Climate Change Service
CDR	Climate Data Record
CEDA	Centre for Environmental Data Analysis
Climate KIC	Climate Knowledge and Innovation Community
CLIPC	Climate Information Platform for Copernicus
CMCC	Centro Euro-Mediterraneo per I Cambiamenti Climatici
CMEMS	Belgian Copernicus Marine Environment Monitoring Service
CMIP	Coupled Model Intercomparison Project (with various phases, e.g. 5)
CRU	University of East Anglia Climate Research Unit
CS	Climate Services
DIG	Data Infrastructure Governance
DKRZ	Deutsches Klimarechenzentrum (German Climate Computing Centre)
DRM	Disaster Risk Management
EC	European Commission
ECMWF	European Centre for Medium Range Weather Forecast
ECV	Essential Climate Variable
EEA	European Environment Agency
EIT	European Institute of Innovation and Technology
EO	Earth Observation
EOSDIS	Earth Observing System Data and Information System
ECA&D	European Climate Assessment & Dataset
ESA	European Space Agency
ESGF	Earth System Grid Federation
EU	European Union

EU-MACS	European Market for Climate Services
EUPORIAS	European Provision Of Regional Impacts Assessments on Seasonal and Decadal Timescales
FMI	Finnish Meteorological Institute
GCOS	Global Climate Observing System
GCOS ECVs	Global Climate Observing System Essential Climate Variables
GFCS	Global Framework for Climate Services
GHCN	Global Historical Climatology Network
IMPACT2C	European Commission project ‘Quantifying projected impacts under 2°C Warming’.
INSPIRE	Infrastructure for Spatial Information in Europe
IPCC	Intergovernmental Panel on Climate Change
IPSL	Institut Pierre Simon Laplace
JPI-Climate	Joint Programming Initiative "Connecting Climate Knowledge for Europe"
KNMI	Royal Netherlands Meteorological Institute
MARCO	MArket Research for Climate services Observatory
MLP	Multi-layer perspective
NAPS	National Adaptation Plans
NASA	National Aeronautics and Space Administration (USA)
NCEI	National Centers for Environmental Information (USA)
NetCDF	Network Common Data Form
NOAA	National Oceanographic and Atmospheric Association (USA)
OSTP	Office of Science and Technology Policy (USA)
PIK	Potsdam Institute for Climate Impact Research
QA	Quality Assured
UNF	Universal Numeric Fingerprint
UNFCCC	United Nations Framework Convention on Climate Change
WMO	World Meteorological Organisation

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1. NON-TECHNCAL SUMMARY

This report, Deliverable 1.3 of EU-MACS, explores how the existing climate data infrastructure inhibits or stimulates the European climate services market. The research presented herein informs the EU-MACS project with hypotheses around additional barriers and enablers to the climate services market stemming from the climate services data infrastructure.

The research presented in this report comprise three individual subtasks based on literature review and the completion of a range of interviews with stakeholders involved in various aspects of the climate data infrastructure domain.

The **first** subtask involved cataloguing and mapping the relationships of organisations involved in the climate data infrastructure value chain. In addition, an evaluation of organisations was undertake based on their influence on infrastructure in Europe. Once the mapping was completed, interviews were conducted with representatives of a sample of the mapped organisations to corroborate the literature research and obtain additional insights.

The **second** subtask comprised a usability survey designed and carried out on the upstream section of the climate services providers catalogue: organisations that operate in EO satellites and/or weather stations. Using a scoring framework consisting of 18-20 indicators that were constructed based on literature on usability heuristics (Molich and Nielsen 1990; Nielsen 1994), and guidelines for user testing (US Department of Human Health Services 2013), a range of climate data websites and portals were evaluated and ranked.

The **third** and final subtask explored data infrastructure governance and in particular the *governance of problems* approach (Hoppe 2010). The task put emphasis one the processual character of data infrastructure governance data infrastructure in Europe as interaction and negotiation. The task was completed through a combination of literature review and stakeholder interviews. Interviews were conducted in order to corroborate preliminary findings and guide further research.

Infrastructure may often be thought of as the physical structures on which information travels. This report expands upon this concept principally through the development of four infrastructure dimensions, including:

a) **Instrumentation Infrastructure** (including but not limited to): weather stations, radar, buildings, projects and partnerships, equipment such as computing facilities and satellites, as well as the practices and personnel, and the organisational set-up and institutional frameworks around these (also included in the following three dimensions);
b) **Information Infrastructure** (including but not limited to): information is data plus meaning and organisation; that which is needed for qualifying (refining, processing) data for climate-related and service-related use, the structure of storage as well as its preparation (curation) for dissemination;
c) **Communication Infrastructure:** the entire machinery of channels where exchanges of climate-related ideas and information take place, which are not considered to be services;
d) **Service Infrastructure:** the machinery of channels where the provision of climate services takes place; including the users (clients, customers, business partners). This infrastructure is the most complex dimension as it relies, on and intersects with, the other three dimensions.

Services, as suggested in this report with regards to climate data service infrastructure, can materialise in products that are more than situated activity; services as things to be taken home, implemented, refined or used further “at home” and perhaps even shared. The quality and fit of a service depend substantially on whether there is anybody on the user side that can engage in communication about data.

Therefore, it is of utmost importance to view the **climate services infrastructure set-up** as one in which users already have their place, instead of being taken as “external factors” to a somewhat closed system. Precisely here, we argue, success or failure of climate services will be determined: in our ability to view and practically embed users as integral and equal partners in the co-construction of climate services.

The research outcomes from the three subtasks are combined to develop a series of **hypotheses for testing** during subsequent phases of the MARCO project. These hypotheses include:

- **Hypothesis 1:** A common data format and a common convention for data records and exchange will boost services and the popularisation of climate data use.
- **Hypothesis 2:** Role-specific data finding aides (e.g. effective search functions and clear navigation), offered with real human interactive support, are crucial for successfully establishing and maintaining data provider/ user relationships.
- **Hypothesis 3:** Climate services philosophies sometimes seem to pin all hopes on either a good portal or a good set of aides; the solution, however, seems to be more of a combination of both, plus a good overview of available data sources, functional methods and active human (personal/personnel) engagement facilitating how users interact with both portals and aides.
- **Hypothesis 4:** The ultimate task of a good data infrastructure governance is to emancipate it (from technical-technocratic restrictions of specialists’ mono-disciplinary ‘boundary working’) into a ‘knowledge infrastructure’ (Edwards 2010) with greater usability and real-world application by other sectors (e.g. use of data by the mining sector).
- **Hypothesis 5:** Boundary objects can provide the chance to let disparate knowledges and interest, positions and conventions converge. There are numerous items that may enhance cooperation across the boundary of climate sciences into other domains (e.g. the boundary between the practices of climate science and law), for example use cases that show the value of climate services (i.e. the business value) to users operating in other, non-climate services, sectors (e.g. aviation or road engineering).
- **Hypothesis 6:** It makes sense that free and open climate data is made accessible through a portal (e.g. Copernicus C3S) when flanked by support and tutorials that enhances inclusivity of a broader user base. Portals need to increase user experience to maximise impact. Freely available data, when it is not combined with appropriate levels of support, can be problematic.

2. INTRODUCTION

Background on EU-MACS

The European Commission (EC) has taken several actions in its current research programme Horizon 2020 (H2020 to support the effective and widespread uptake of climate services. These actions are guided by the European Research and Innovation Roadmap for Climate Services (c.f. European Commission 2015), which addresses the three main challenges of enabling market growth, building the market framework and enhancing the quality and relevance of climate services.

EU-MACS, and its sister project MARCO, deal with the analysis of various dimensions of the climate services market. In addition, the EC funded a number of demonstration projects to investigate the added value of climate services sectors with hitherto little uptake of climate services (SC5-01-2016-2017), while other projects focussed on building a more effective network of relevant climate services actors (e.g. ERA-NET for Climate Services (SC5-02-2015) and a project funded under the Coordination and Support Action (SC5-05b-2015) called Climateurope).

An important sub-programme in H2020 is the COPERNICUS Climate Change Service (C3S). C3S aims to generate a comprehensive, coherent and quality assured climate data set to support mitigation and adaptation planning, implementation and monitoring.

Overall, EU-MACS 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. The remainder of this report deals with a particularly element of this research, the analysis of existing data infrastructure for climate services.

Overview of Deliverable 1.3

This report, Deliverable 1.3 of EU-MACS, will explore how the existing climate data infrastructure inhibits or stimulates the European climate services market. The research presented herein informs the EU-MACS project with hypotheses around additional barriers and enablers to the climate services market stemming from the climate services data infrastructure.

This research report is complemented by Deliverable 1.1 and 1.2. Deliverable 1.1 investigates existing market structures and dynamics (e.g. which users are involved in the climate services market, what roles do users play in the market, and what are the main market-based enablers and barriers to sectoral growth). Deliverable 1.2 investigates the current resourcing and business models of the supply and use of climate services, as well as existing principles and practices in quality assurance. Taken together, these reports provide a snap shot current market conditions and innovation prospects in the climate service market in Europe.

Infrastructure may often be thought of as the physical structures on which information travels. This report expands upon this concept by exploring a more complex understanding of climate services data infrastructure. It reviews the structures behind the climate data collection, matching, storage, distribution, refinement into further products, further distribution, and processing. The work also includes extensive discussion on governance around these activities. A fair amount of unpacking is needed around these terms, which is provided in the following section. Both practical (see sub-tasks 1 and 2 developed by Acclimatise) and theoretical (see sub-task 3 developed by University of Twente) analysis of the climate services data infrastructure and governance are undertaken.

Terms and Definitions

Definitions for terms such as ‘climate services’ and ‘climate data’ are somewhat ambiguous, and are still under debate. This often leads to misunderstandings and potential misuse. For instance, during the course of this research, there were several instances where the term ‘climate data’ was used colloquially to mean an array of different things, such as observational data, climate data records, climate models and climate projections. This section offers clarification and elaboration on the following terms, also indicating how they are used in this report: climate data (including observational data, climate data record, climate models, climate projections), services, climate services (including upstream and downstream), infrastructure and governance.

Climate Data

The term ‘climate data’ is not a definite term, rather it is a phrase used to denominate a range of data products that relate to climate. These include observational data and climate data records, climate models, and climate projections, which are explained below.

This report refers to **observational data** as data collected by instruments either on the Earth’s surface (weather stations) or from space (Earth Observation instruments) (UK Met Office 2016). Climate-related observational data focuses on variables relevant to the climate system. The Global Climate Observing System (GCOS) defined 50 Essential Climate Variables (ECVs) to support the work of the UN Framework Convention on Climate Change (UNFCCC) and the Intergovernmental Panel on Climate Change (IPCC). The standardisation of these variables allows for international exchange of current and historical observations (WMO n.d.). The ECVs can be seen in

Table 1 below

The National Research Council defines the **climate data record** (CDR) as "*a time series of measurements of sufficient length, consistency, and continuity to determine climate variability and change*" (National Research Council 2004). These CDRs are comprised observational data. In their very essence, **climate models** are "*mathematical representation[s] of the climate system based on physical, biological, and chemical principles*" (Université catholique de Louvain 2008). They are the tools that produce **climate projections, and climate simulations of current and past climate**. Observational data and CDRs can be used to validate the results produced by climate models for the past. By modelling the climate of past decades and comparing the statistics of the results to the statistics of the observations over the same time period, scientists can test the accuracy of their models. Climate re-analysis acts as an intermediary form; it gives a numerical description of the recent climate, produced by combining models with observations (ECMWF n.d.).

TABLE 1: GCOS ESENTIAL CLIMATE VARIABLES CLUSTERED BY DOMAIN

Domain	GCOS Essential Climate Variables
Atmospheric (over land, sea and ice)	**Surface**: Air temperature, Wind speed and direction, Water vapour, Pressure, Precipitation, Surface radiation budget.
	Upper-air: 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, Ozone and Aerosol, supported by their precursors.
Oceanic	**Surface**: 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.

Services

A service activity is seen here as a sort of negotiation, in which providers and users interact upon a problem, and services providers deliver their services (Gadrey 2002):

- in this interaction as service relationship;
- in an output that consists in ‘tailored information’;
- in an organisation (an external supercomputing centre or an organisational unit in-house) that maintains a service; and
- in a product or good, like a report that can be used for decision-making and which is more than “just” the tailored data.

Services can materialise in products that are more than situated activity; services are things to be taken home (to a public or private body, or even by an individual citizen), implemented, refined or used further “at home” and perhaps even materially shared with other users there. Services can be offered, requested, provided, used – they are a give-and-take-relationship.

Climate Services

The term ‘climate services’ is relatively new and as such has no set definition. This report will, as will the other deliverables of the EU-MACS project, use the European Commission’s definition, which describes climate services as: “*the transformation of climate-related data – together with other relevant information – into customised products such as projections, forecasts, information, trends, economic analysis, assessments (including technology assessment), counselling on best practices, development and evaluation of solutions and any other service in relation to climate that may be of use for the society at large. As such, these services* *include data, information and knowledge that support adaptation, mitigation and disaster risk management (DRM)*" (European Commission 2015).

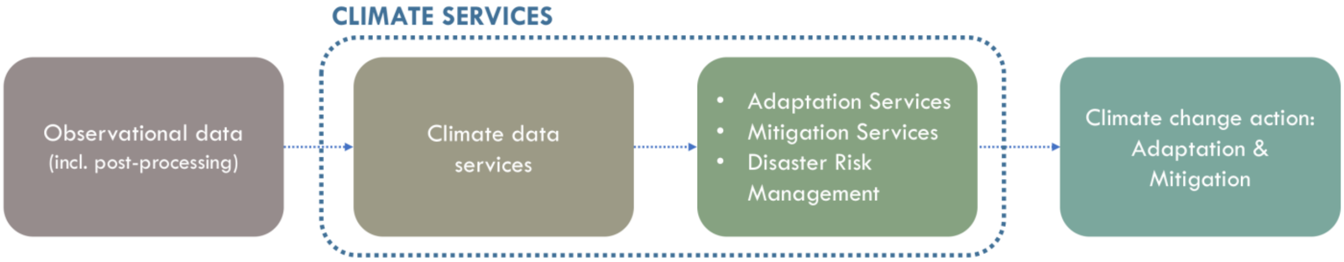

FIGURE 1: SIMPLIFIED CLIMATE SERVICES DIAGRAM BASED ON EUROPEAN ROADMAP FOR CLIMATE SERVICES

Figure 1 offers a graphical representation of this definition. In it, climate data services, referring to climate data records, projections, forecasts, and climate models, are separated from adaptation, mitigation and disaster risk management services, which include vulnerability and risk analyses, recommendations for climate change action, and more refined information. The dotted line around the two boxes in the middle symbolises the fluidity of the climate services boundaries, driven by numerous technological, scientific and market-based forces. For examples of climate services products in each step of the supply/value chain, please see actors

Error! Not a valid bookmark self-reference. indicates climate services products typically associated with each for the four boxes shown in Figure 2.

Table 2, p.20).

This report will focus primarily on the first two boxes of the diagram, as it analyses climate data infrastructures. Data services and products are more concentrated in the left side of the diagram. However, the third and fourth box will also be briefly considered.

Upstream and downstream climate services

The upstream climate services sector includes actors in the first box of Figure 1, which includes actors involved in the value chain leading to an operational Earth Observation (EO) space system. In simpler terms, those actors that provide and manage the infrastructure and instruments with which data is recorded, e.g. EO programmes of space agencies (European Commission 2016b).

The downstream sector includes those that exploit EO data and provide EO-related products and services to users (European Commission 2016b). For the purpose of this report, this mostly includes actors in the second and third boxes. Although, as will be shown later, the boundaries are not clear, e.g. space agencies run EO programmes but, to a certain degree, also refine the recorded data into EO data products. Climate models and weather forecasts are at the very beginning of the downstream sector, or even midstream, while climate information products (e.g. climate risk assessments) are further to the right.

Climate Services Data Infrastructure

The provision of climate services relies on an infrastructure as an underlying foundation and framework. This infrastructure is more than just a physical structure upon which services operate that is obsolete once built. Rather, the climate services infrastructure is constantly being created. This infrastructure emerges in relation to organised practices. A realist view on climate services infrastructure conceives it as "*something that emerges for people in practice, connected to activities and structures*" (Star and Ruhleder 1996: 112). Thus, it includes social, material, technical and business-related, scientific and governance dimensions on which climate services travel. Tasks like processing or visualisation of data may be linked to more than just one dimension of the infrastructure, depending on whether the building of a meaningful corpus of data is the objective (information dimension) or rather the exchange within the climate research and services community (communication); it may even address both. Climate services infrastructure in this understanding is comprised of four dimensions:

e) **Instrumentation Infrastructure** (including but not limited to): weather stations, radar, buildings, projects and partnerships, equipment such as computing facilities and satellites, as well as the practices and personnel, and the organisational set-up and institutional framework around these; this is what allows for the collection of all kinds of climate-related data;
f) **Information Infrastructure** (including but not limited to): information is data plus meaning and organisation; that which is needed for qualifying (refining, processing) data for climate-related and service-related use, the structure of storage as well as its preparation (curation) for dissemination; often linked with non-climate data, and is based also on social practices, personnel, and the organisational set-up and institutional framework around these;
g) **Communication Infrastructure:** the entire machinery of channels where exchanges of climate-related ideas and information take place, which are not considered to be services; before any service is given, the collectors and processors of data and information need to be in meaningful exchange about data and information (share all this or first of all exchange ideas about what could be worth sharing or using for particular purposes; conventions and other shared rules of use are negotiated by communication); the fora, platforms, arenas where personnel work in and are interested in, relating to climate data and information; including the institutional and organisational structures as well as personnel needed for the service activities;
h) **Service Infrastructure:** the machinery of channels where the provision of climate services takes place; including the users (clients, customers, business partners), as they bring their sets of ideas about why and how they would use climate services (either in mere reaction to which services are offered or in an attempt at co-production); including the institutional and organisational structures as well as personnel needed for the service activities. This infrastructure is the most complex dimension as it relies, on and intersects with, the other three dimensions.

These dimensions are the result of the analyses of climate services infrastructure governance presented in sub-task 3, where the four dimensions will be explained in some more detail.

Governance[1]

A simple definition of governance, for the purposes of this report, is the establishing, maintaining, changing (Borrás and Edler 2014) and sometimes even de-aligning or terminating (P. Stegmaier, Kuhlmann, and

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[1] See sub-task 3 for further explorations on governance.

Visser 2014) of a social order in a political-administrative-managerial view (Colebatch 2009). Governance means reacting on emerging or ongoing dynamics (Geels 2002; Rip 2012; Turnheim and Geels 2012) or the active, purposeful intervention on a socio-technical system like climate observation, a policy area like the EU turn from fossil energy to decarbonisation, or a business sector like climate services. In the case of this project, discussion on governance efforts to build, and stabilise interrelations and interactions of a market (Callon 1998) for climate services can be found. Governance as active practice entails struggling about defining a problem, setting problem definitions on agendas, developing, negotiating and selecting policy alternatives, as well as the politics of preparing and taking binding decisions (Kingdon 2011) as windows of opportunity open up.

Methodology

A literature review was carried out to investigate and clarify terminology around the climate services data infrastructure (see p. 9), to establish important trends in the infrastructure, to investigate which dimensions of the infrastructure have been studied and developed, and to ascertain which areas of the infrastructure may be hindering or enabling the further development of the climate services market. Both scientific and grey literature was consulted. Following the literature review, this research was split into several sub-tasks.

First, a database of climate services providers and users was compiled (herewith called the 'CS actors database'), cataloguing organisations ranging from observational data providers to downstream users. This was achieved by mapping actors to, for example, distinguish between entities who operate Earth Observation (EO) satellites and/or weather stations (upstream climate services), and those who use satellite-based and other data for high-level complicated analyses or similar (e.g. forecasts, climate models) (downstream climate services). In addition, actors were mapped based on their influence on infrastructure in Europe. Mapping these actors elucidates the ways data is refined, allowing for further conclusions to be drawn out. Once initial findings were made, expert interviews were conducted to corroborate and fortify these findings. While this catalogue and mapping exercise was not exhaustive, it allowed for useful insight into the broad range of actors present in climate services, their relationships, and highlighted how data is refined and processed along the value chain. **This is sub-task 1.**

Second, a usability survey was designed and carried out on the upstream section of the climate services providers catalogue: organisations that operate in EO satellites and/or weather stations. These organisations were of interest given the longstanding and strong focus on upstream observational data in the climate services sector and its use in the compilation of climate data records (see p. 9 for further discussion). Please refer to p. 30 for a detailed description of this survey and its design and the results. **This is sub-task 2.**

Finally, analysis around the data infrastructure governance (DIG) was conducted to identify typical governance problems related to climate services related data infrastructures. The task developed a first account of the multi-layered nature of data-related infrastructure (now sub-divided into instrumentation, information, communication, and services infrastructures). For these purposes, the analysis looked into the field of 'enactors', those creating and enacting new options for climate services in terms of data infrastructure and its governance, 'promoters' who carry and push technological change/climate services data infrastructure innovation and 'selectors', those selecting new options, such as regulators, policy-makers, clients, users/re-users, interest groups, etc.[2] Policy documents, including many reports of European and

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[2] It is prudent to identify enactors/selectors for both the climate data and climate services separately. The climate services providers act as selectors when it comes to the underlying data and as enactors when it comes to the services.

international initiatives for coordinating and building data infrastructures and climate services have been analysed. Expert interviews further informed this conceptual analysis. Both have been amended by scholarly literature on climate services, socio-technical regimes (Grin, Rotmans, and Schot 2010) and information infrastructure governance (Pelizza and Hoppe 2015; Pelizza 2016; Star and Ruhleder 1996). The analysis was based on an iterative logic, where we followed the discourses and actors carrying them (Yanow 2000). Conceptualisation here relies on a general *governance of problems* point of view (Hoppe 2010), which takes practical aspects into account. A Foucauldian approach to discourses is also deployed to determine how discourses inform us about the *order of the things* under investigation (Foucault 1970). **This is sub-task 3.**

Throughout the research, expert interviews were conducted in order to corroborate preliminary findings and guide further research. When interview data is quoted, the following reference format is used: "(Int1-1; 160:3)". First, the anonymised name of the interview is given, then the quotation that was coded in ATLAS.ti, a software package for managing qualitative data analysis.

Limitations

A primary limitation of the research was that it was not possible to conduct an exhaustive characterisation of the climate services data infrastructure for sub-task 1. The database was a collaboration between several researchers, so remains a robust snapshot, though organisations may have been overlooked, if, for example they are new or less well known.

The usability survey, sub-task 2, was also limited in its scope – it only assessed a limited number of data portals in the upstream area of the climate services spectrum. As such, its findings relate to that area only: websites or portals that provide observational datasets from satellites. Focus on this area of the climate services spectrum was an intentional choice, as the intention was to test how easy it is to access data upon which many other services are built. If more time was allowed, the authors would have liked to study usability of more downstream climate services interfaces as well. It was also not possible to survey every type of data portal. Websites hosting climate models and output, for example, were too complex to navigate for a novice user, which was the intended frame of reference. Surveying these other portals and sites could make for another area of interesting research and assessment, especially given the expected growth trajectory of climate model datasets and analysis (Overpeck et al. 2011). Finally, the design of the usability survey did not work on every type of website because websites often hosted very different types of information. Therefore, the usability survey, on a few occasions, had to be diluted to finding any dataset rather than the one specified in the survey design.

The sub-task 3 review on governance of data infrastructure is not meant as an exhaustive stock-taking, but rather as explorative collection of crucial issues identified in the expert interviews and from literature.

3. LITERATURE REVIEW

Established and evolving instrumentation and information dimensions

Edwards (2010) uses the phrase 'climate knowledge infrastructure', to mean the 'many interlocking technical systems' around the collection and assembly of observations and models of physical systems, which are used to collect knowledge about the climate. This report understands this as the instrumentation and perhaps aspects of the information dimensions of the climate services data infrastructure (see Figure 2). This 'vast machine' that collects land, sea, air, and space observations and which models individual physical systems (e.g. atmosphere, ocean) is now nearly complete, according to Edwards. Edwards further characterises the history and state of the infrastructure:

"The climate knowledge infrastructure is built around and on top of weather information systems. It also, and increasingly, possesses information systems of its own. It too is old and robust; it too has passed through many rounds of revision. Yet unlike weather forecasting, climate knowledge — so far — remains very much present, obstinately failing to recede noiselessly into the background. Instead, climate controversies constantly lead down into the guts of the infrastructure, inverting it and reviving, over and over again, debates about the origins of number" (Edwards 2010, 432).

Edwards tells us, despite ongoing scrutiny, the foundation of the climate services data infrastructure is now well established. Overpeck et al. (2010) highlight that this 'vast machine' goes beyond observational data, and that climate data instrumentation now includes model-based "reanalyses", including 'hybrid model-observational datasets created by assimilating observations into a global or regional forecast model for a given time period' (701). In describing the recent boom of numerical climate model simulations, they call attention to ways this new boom of data can both advance and inhibit the further development of climate services.

Advancements include the development of collaborative efforts such as the Coupled Model Intercomparison Project (CMIP), which in theory should allow for anyone to access the model outputs for analysis and research (701). Williams et al. (2009) confirm similar advances in the information infrastructure when describing the development of the Earth System Grid Federation (ESGF). Stemming from the Earth System Grid Center for Enabling Technologies (ESG-CET), the ESGF in the US aims is to 'catalog and widely publish distributed climate data so as to make it easily accessible to an international community of potential users'. The Grid includes provisions for metadata and security standards, data transport, aggregation, subsetting, and monitoring of system and services usage (201).

In Europe, the development of programmes such as the Programme for Integrated Earth System Modelling (PRISM) and the European Network for Earth System Modelling (ENES) more generally, have made great strides toward integrating the European climate modeling community (European Network for Earth System Modelling 2011).

Challenges which remain revolve around the sheer amount of climate data being produced. Though the most recent phase of the CMIP was phase 5, phase 3 alone resulted in 36 terabytes of model data alone. The issue with the vast amounts of data is, of course, not only the coordination and storage of it, but also 'how to actually look at and use the data, all the while understanding uncertainties' (Overpeck et al. 2011, 702). While the sophistication and maturity of the instrumentation and information dimensions of the climate services data infrastructure are impressive, the literature indicates there is still some way to go in terms of developing the communication and services infrastructures. This immense amount of data, no matter how impressive, could hinder the climate services market if effective communication infrastructure is not put in place.

Developing communication dimensions of the infrastructure

An early call for the development of the communication dimension of the Climate Services data infrastructure came from the Royal Netherlands Meteorological Institute (KNMI). In 2005, KNMI's asserted that much like GIS, there should be further development of climate-related tools, which use large amounts of spatio-temporal data to inform decision-makers. Data policies around the varying datasets were assumed to be a key barrier to their development (van der Wel 2005). Though this early call could have envisaged the development of downstream tools, such as guidance and processed forms of raw data, it may have contributed more than originally expected to the plethora of upstream portals now present in the climate services market in Europe, as the number of upstream portals have greatly expanded since then.

Web-based portals show up in the literature frequently, as they have been seen as an effective means for communication of large and complex datasets. Williams et al. (2009), when discussing the ESG, proposed the development of a web-based portal to address the needs to assemble, analyze, archive, and access climate modeling datasets, for example. A recent investigation into the ways in which the U.S. government can improve the usability of its climate data has some interesting findings relating to the digital key components of the data infrastructure as well. Key findings were that neither data sets nor portals per se are enough, but that accompanying aides/manuals/assessing tools, personal support, etc. are needed alongside the data (NASA, NOAA, and OSTP 2016).

The EC has recently financed several large studies around various aspects of its flagship earth observation programme, Copernicus, which highlight important findings relating to the need for communication infrastructure development. One study focussed on developing the Copernicus user uptake strategy indicates the data and information access is a key barrier to user uptake. The study also highlights the fragmented nature of this corner of the overall infrastructure – in highlighting the fact that Copernicus portals are not centralised and are dispersed over several websites. Furthermore, the study finds the Copernicus websites lack content which reflect the knowledge levels of the users, and provide a limited amount of information for private sector stakeholders. The study suggests several solutions: a Data Access Information Kit could be provided to potential users at conferences and events, open data discovery functions on the data portals could be enabled, and portals could be more user friendly (European Commission 2016a).

These high-level American and European studies mirror the findings of another study, which found that climate services need to tackle the challenge of co-designing and co-generating climate services alongside users. Specifically, it was found that “bridging the ‘valley of death’ between providers and end users is recognized as a key issue however there is little consensus on how this should be done” (Buontempo et al. 2014, 2).

Increasing institutional dimensions of the infrastructure

RESEARCH

The Global Research Data Infrastructures 2020 Final Roadmap (CNR-ISTI 2012) calls for supporting institutions behind disciplines, like climate science, where new high-throughput scientific instruments, telescopes, satellites, accelerators, supercomputers, sensor networks and running simulations are generating vast amounts of data. The Roadmap specifically asserts that 'global research data infrastructures' need to be in place to ensure new techniques and technologies continue to exploit the volumes of data being produced. 'Global research data infrastructures' refers to "*managed networked environments for digital research data consisting of services and tools that support: (i) the whole research cycle, (ii) the movement of research data across scientific disciplines, (iii) the creation of open linked data spaces by connecting datasets from diverse disciplines, (iv) the management of scientific workflows, (v) the interoperation between research data and literature and (vi) an integrated Science Policy Framework*." (CNR-ISTI 2012: 8) Ultimately this should reduce geographic, temporal, social, and national barriers in order to allow for the discovery, access, and use of data.

At the European level, there is one main initiative to support the development of climate services, the Copernicus Earth Observation Programme. Based on the operational services of past research promoted by the European Space Agency (ESA) and the 7th Framework Programme for Research and Technological Development (FP7), as well as emerging research from Horizon2020, the 8th Framework Programme, Copernicus will provide a satellite and ground-based observation system. Additionally, Copernicus is developing an operational climate service, the Copernicus Climate Change Service (C3S), including data from seasonal to decadal climate modelling (European Commission 2014).

Currently, Copernicus and Horizon2020 are the main sources of funding for operational Climate Services and for Climate Services-related research and innovation. Horizon2020, for example, also funds activities of the European Institute of Innovation and Technology (EIT), which supports the Climate Knowledge and Innovation Community (Climate KIC), a programme that includes climate services development among its main objectives. Furthermore, ESA's Climate Change Initiative is generating a subset of the Global Climate Observing System (GCOS) Essential Climate Variables (ECVs) using its EO data and archives. The JPI-Climate Joint Programme Initiative aims at aligning national climate-related research priorities and has a module directly dedicated to the research and development of Climate Services. Its European Research Area for Climate Services (ERA4CS) will potentially provide support for numerous aspects of the climate services data infrastructure, though how remains to be seen. Finally, the European Climate Adaptation Platform (Climate ADAPT) offers a web-based reference tool, hosted and managed by the European Environment Agency (EEA), that can help the development of adaptation-related climate services. While Climate ADAPT is a useful store of information, it should be noted that this resource does not provide upstream climate-related data and information.

ETHICS AND QUALITY ASSURANCE

A recent paper (Adams et al. 2015) calls on climate services providers to establish ethical standards around the practice and production of climate services, indicating this aspect of the infrastructure has room for development (see below, sub-task 3, (13-16)).

In relation to the institutions around the upstream aspects of the infrastructure, the Quality Assurance for Essential Climate Variables (QA4ECV) project (Nightingale et al. 2016) has been established to help deliver quality satellite derived datasets in support of the European Union's Earth Observation Programmes Copernicus Climate Change Service. One remaining issue is that it is not always possible to determine what 'quality' means for different users and purposes; users of the data were found to be interested in quality assured (QA) information, but that there remains progress to be made in developing QA information across products evenly (e.g. atmospheric products has more readily available QA information than for ocean and land products) (Nightingale et al. 2016.).

4. RESULTS

Sub-task 1: Mapping climate data services providers & users

Data is gradually processed from upstream to downstream, from recording it to producing reports or analyses that feeds into national adaptation plans (NAPs), or emission targets, and a wide array of climate action-related decisions. Most of the actors identified during the research do not fit neatly into one of the segments in Figure 1 (p. 11); often, actors will cover more than one of the steps in the data refinement process. This exercise therefore highlights the fuzzy nature of the upstream and downstream divide present in climate services.

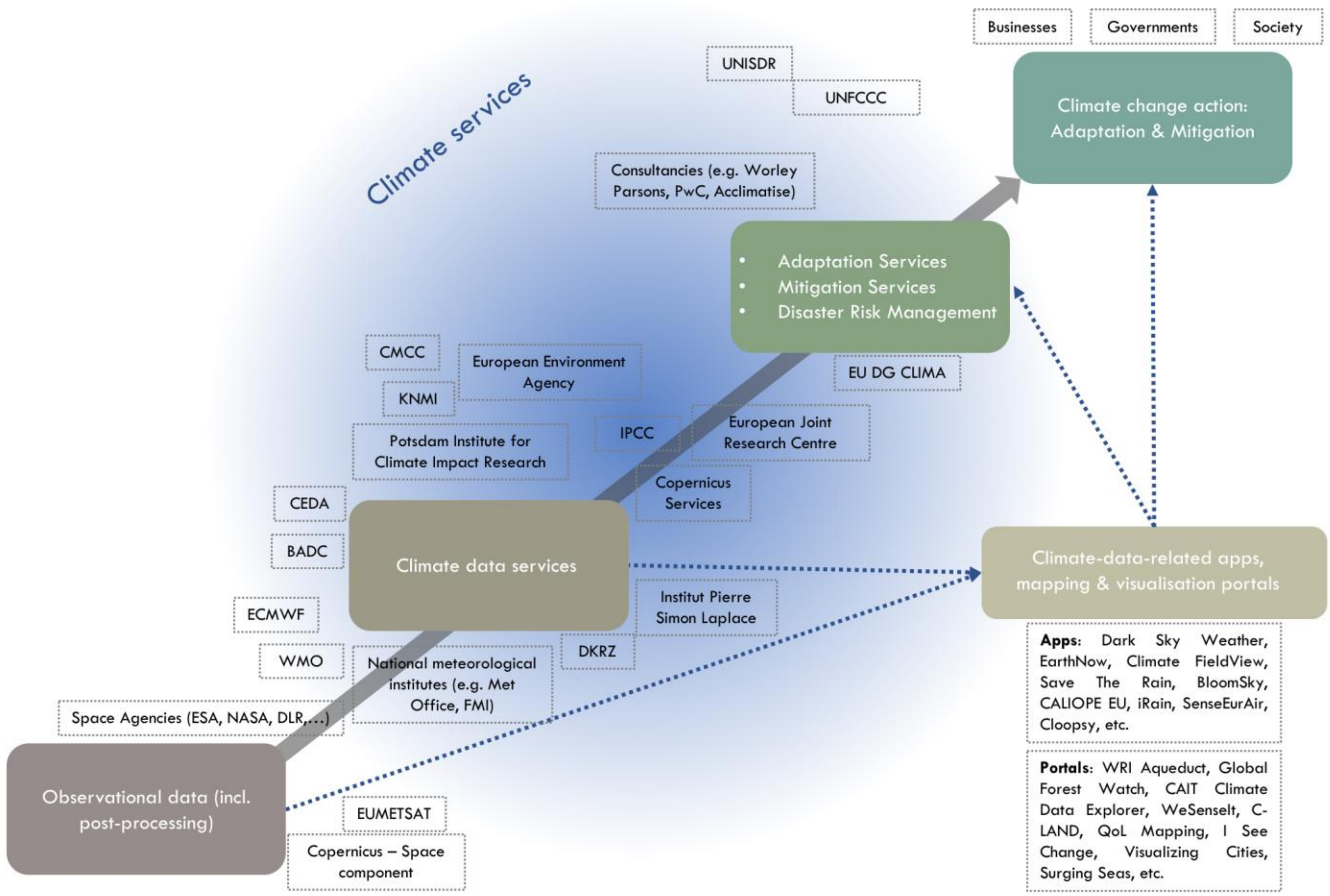


Figure 2 offers a simplified mapping of data providers and users with a sample of organisations and actors present along the climate services value chain, helping to illustrate the fluidity of the service infrastructure.

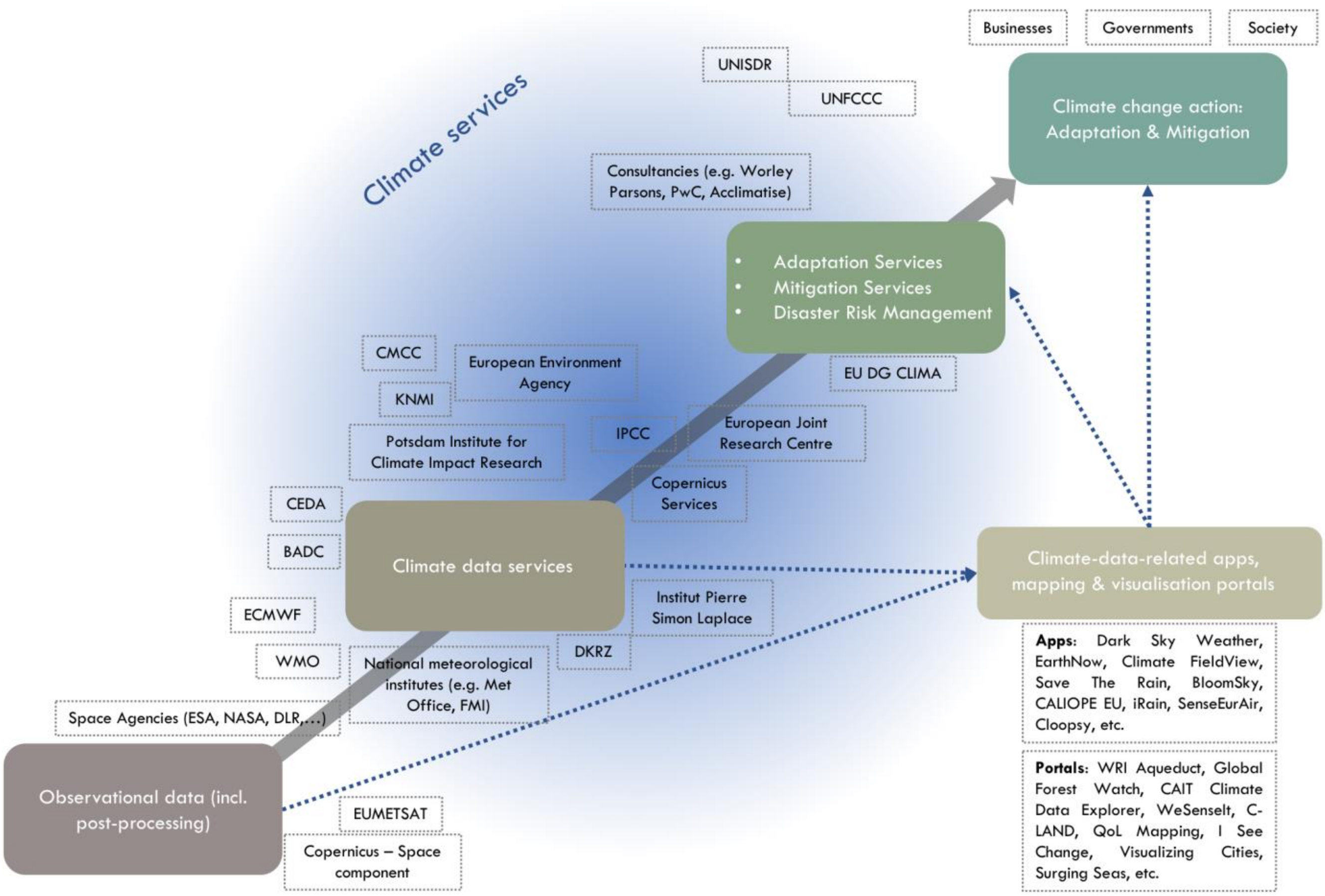


FIGURE 2: MAPPING CLIMATE SERVICES ACTORS

Error! Not a valid bookmark self-reference. indicates climate services products typically associated with each for the four boxes shown in Figure 2.

TABLE 2: EXAMPLES OF CLIMATE SERVICES PRODUCTS IN EACH STEP OF THE SUPPLY/VALUE CHAIN

Satellite and in-situ based observational data	Climate data services	Adaptation and mitigation services, disaster risk management	Climate action
Satellite imagery, atmospheric measurements, precipitation, temperature, humidity, …	Climate data records, climate models and projections, seasonal/ medium range forecasting regional downscaling, mapping and analysis tools, portals for accessing and processing climate data …	Climate risk assessments, vulnerability assessments, synergies with disaster risk planning and relevant mitigation efforts, …	National Adaptation Plans (NAP), specific adaptation action, resilience building, renewable energy investments, …

The following section provides further details related to each step of the value/ supply chain.

OBSERVATIONAL DATA - SATELLITE

For space-based data, the data is measured and recorded by instruments mounted on satellites. The Earth Observing System Data and Information System (EOSDIS), a key core capability of NASA's Earth Science Data Systems Program, has a set of defined data processing levels ranging from Level 0 to Level 4. At the very beginning, Level 0, the data is unprocessed instrument data, or raw data; Level 4 describes modelled outputs or variables derived from multiple measurements (NASA n.d.). In Table 3 all six processing levels can be seen.

TABLE 3 EOSDIS DATA PROCESSING LEVELS

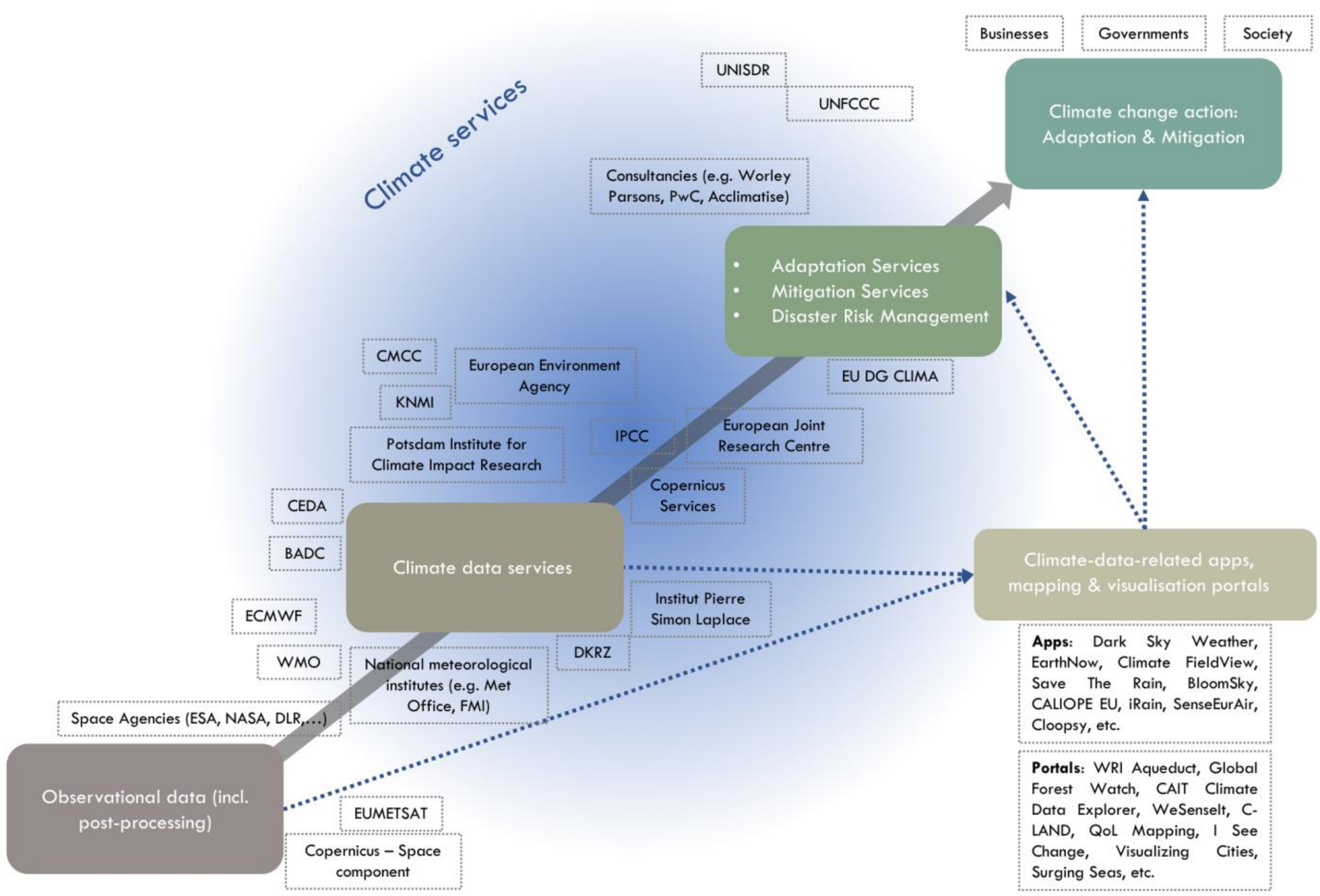
Data Level	Description
0	Reconstructed, unprocessed instrument and payload data at full resolution, with any and all communications artifacts (e.g., synchronization frames, communications headers, duplicate data) removed.
1A	Reconstructed, unprocessed instrument data at full resolution, time-referenced, and annotated with ancillary information, including radiometric and geometric calibration coefficients and georeferencing parameters (e.g., platform ephemeris) computed and appended but not applied to Level 0 data.
1B	Level 1A data that have been processed to sensor units (not all instruments have Level 1B source data).
2	Derived geophysical variables at the same resolution and location as Level 1 source data.
3	Variables mapped on uniform space-time grid scales, usually with some completeness and consistency.
4	Model output or results from analyses of lower-level data (e.g. variables derived from multiple measurements).

OBSERVATIONAL DATA - IN-SITU

In-situ data contributes to climate data records. It is recorded by weather stations in specific locations and instruments on aircrafts, buoys, etc. Weather stations will give accurate measurements of ground conditions but can sometimes require interpolation when data is missing. Satellites provide complete spatial coverage of various parameters but can have difficulties recording certain ground conditions, like precipitation (Mendelsohn et al. 2007). Thus, combinations of data from both in-situ and space-based instruments are important. For example, the Copernicus Programme puts an enormous emphasis on its satellites, but also uses data from in-situ instruments.

These data are most commonly processed by the space agencies that operate Earth Observation (EO) satellites and the meteorological institutes who run weather stations and participate in satellite missions. However, following the processing of data already becomes difficult at these early stages. Satellite and, sometimes, weather-station data can be acquired, with very low levels of processing applied to it, open and free from e.g. ESA, NASA, NCEI, and Copernicus. Data at this stage has been noted by experts to often have resolution or formatting issues. In the UK, for example, obtaining data for a certain variable in a certain location may require the download of all files for that variable, for the whole of the UK, for that time period (Int1-3). While it is unclear if this is the case in other countries, it is clear that there does not appear to be a best-practice for this across Europe. There are, however, efforts like the climate4impact portal[3] which offer search filters to provide a more user-friendly data retrieval experience (see also sub-task 3, on ‘access’).

CLIMATE DATA SERVICES



The ‘climate data services’ segment of Figure 2 comprises activities that focus mainly on climate modelling, climate projections, and forecasting. These are highly-specialised activities that are typically undertaken by research-orientated organisations, many of which are also represented in the earlier segment of ‘Observational data (including post-processing)’, e.g. NASA. Climate modelling requires, apart from very specific scientific education, vast sources of computing power and is thus not an activity that can be taken up easily. In Europe, ESGF members like British Atmospheric Data Centre (BADC), Centro Euro-Mediterraneo per I Cambiamenti Climatici (CMCC), German Climate Computing Centre (DKRZ – Deutsches Klimarechenzentrum), and Institut Pierre Simon Laplace (IPSL) are well known organisations that manage and analyse climate data. Others include Barcelona Supercomputing Centre, the University of East Anglia Climate Research Unit (CRU), Potsdam Institute for Climate Impact Research (PIK) and meteorological institutes such as the Royal Netherlands Meteorological Institute (KNMI), or the Finnish Meteorological Institute (FMI).

CLIMATE-DATA-RELATED APPLICATIONS AND VISUALISATION PORTALS

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[3] See: https://climate4impact.eu/

Stemming from observational data and climate data services, climate-related applications, mapping, and visualisation portals (see Figure 3) is an emerging area of the climate services data infrastructure. Increasingly, climate services providers and purveyors are taking advantage of the wealth of data available, finding innovative ways to use it to provide services. These apps and tools are not strictly related to climate services, with some using climate and climate-related data being used for other end uses. Case study 2 (p.29) highlights examples of newly developed apps and tools.

COORDINATION EFFORTS

As evidenced by Figure 3, there are many sources, types and formats of climate-related data used by actors along the climate services value chain. An important part of the climate services data infrastructure are institutions and organisations which facilitate the coordination and formatting of these data. Numerous efforts exist, which help facilitate the production of climate services. The Global Historical Climatology Network (GHCN), for example, works to integrate and standardise climate summaries from surface stations – from data 100+ years old, into contemporary data formats. The Infrastructure for Spatial Information in Europe (INSPIRE) Directive in Europe addresses 34 spatial data themes needed for environmental applications and allows for sharing of environmental spatial information to the public and between organisations. With regards to climate data stemming from model output, linking and matching is completed by organisations such as ESGF and ENES.

Discussion

OPEN AND FREE ACCESS TO DATA

Climate projections, (re)analyses and results of models are used further downstream in the climate services segment 'Climate Adaptation, Mitigation, and Disaster Risk Management (DRM) Services' (see Figure 1), where businesses like consultancies take supplied data and use it for climate vulnerability and risk assessments, reports, or maybe even to develop their own proprietary tools. Depending on what data is needed for these products, it can be purchased from organisations like UK Met Office or Potsdam Institute for Climate Impact Research (PIK), or acquired for free from e.g. KNMI's Climate Change Atlas.[4] However, purchasing data remains a key barrier to the uptake of climate services (Int1-3). Soon, Copernicus C3S, implemented by ECMWF, will start offering a range of different, free-of-charge and openly licensed climate data products from climate re-analyses and seasonal forecasts to future projections.[5] It is worth mentioning that some datasets can be used freely for research or non-commercial use, but have to be purchased for commercial use, other datasets might only be available for certain uses.[6] Tensions around open and free data remain; having a major actor like Copernicus C3S offering a large range of free and open climate data products will likely be felt by actors selling similar products. Downstream users like consultancies are likely to profit from free C3S products, as will universities and research institutions with budget restrictions. However, they also need the knowledge and expertise to use these data properly. Also, while free and open data sources expand, the issue of paying for these networks will not cease to exist. The instrumentation involved in this alone is expensive and requires constant maintenance. Continual funding of this infrastructure will require at very least strong political will, and could involve cost recovery (Int1-3).

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[4] Climate Change Atlas by KNMI: https://climexp.knmi.nl/plot_atlas_form.py?id=someone@somewhere

[5] Copernicus Climate Change Service (2017). About C3S. Web document: https://climate.copernicus.eu/about-c3s

[6] See for example ESA Earth Observation Data Policy: https://earth.esa.int/web/guest/-/revised-esa-earth-observation-data-policy-7098

Tracing how open and free data is further processed is difficult. In a presentation given at the American Meteorological Society, the US National Centers for Environmental Information (NCEI) explained that until recently, they were unable to track exactly what sector their users come from and why they access NCEI data. Tracing users has, however, allowed for an improved understanding of which sectors use the data, what products are being used, and ultimately how best to meet their needs. Voluntary registration processes allow for actors to get a better idea of who downloads data for what purpose (NOAA, NESDIS, and NCEI 2017). One other consideration around users, is that knowing who users are could allow for tailored cost-recuperation Tracing users would allow for insight into the potential to recoup all or a portion of these costs from users who may then be profiting from the use of free and open data. Cost recuperation remains a healthy debate in the climate services sector, however, as open and free access to data, regardless of the end use (commercial or otherwise) is seen by many as the foundation of climate action.

See Case Study 1, p. **Error! Bookmark not defined.**, for a review of how the Copernicus Marine data-portal site traces users, and what insight that might provide.

PORTAL PROLIFERATION

A frequent means of dissemination of data is via web-based portals, indicated in

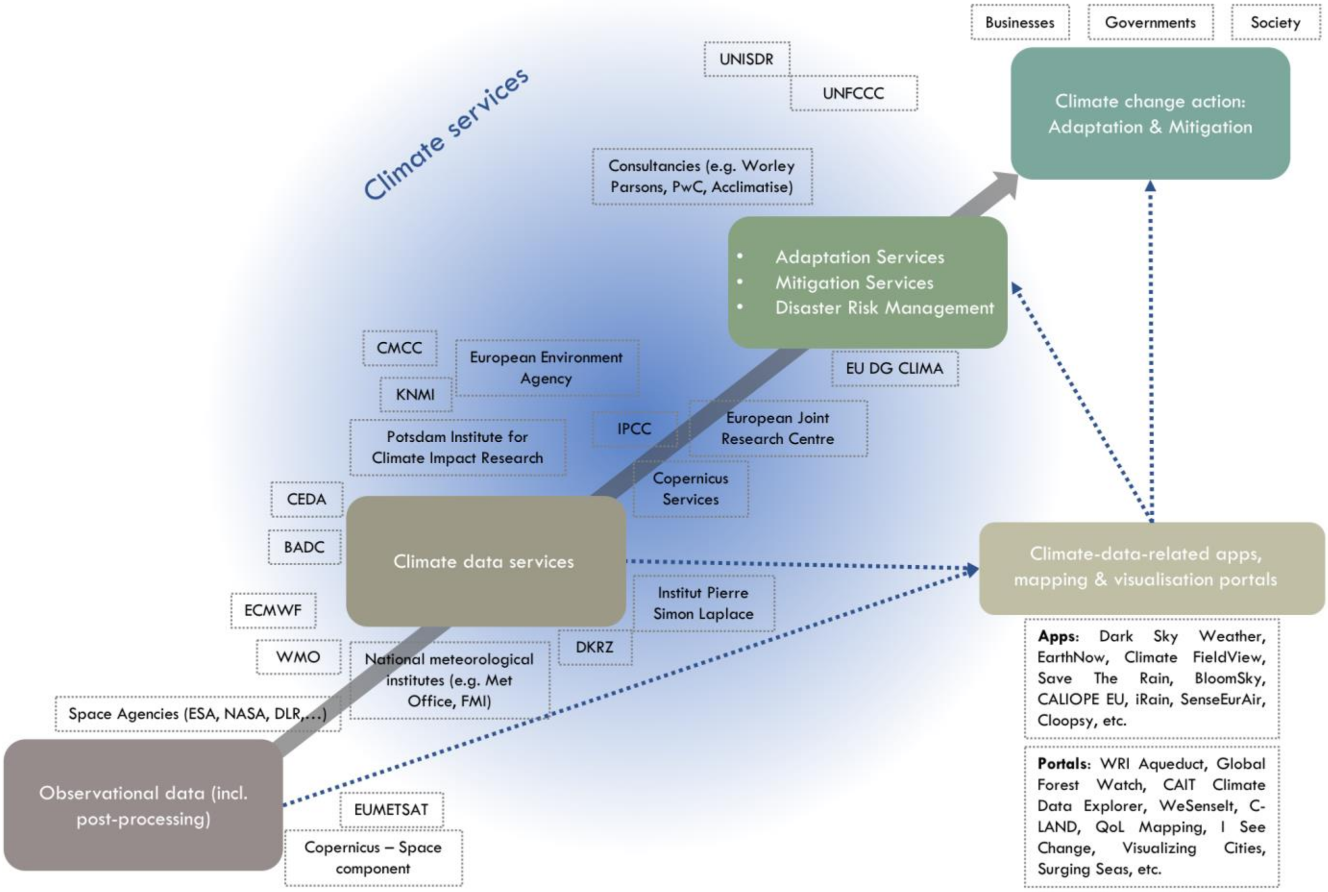


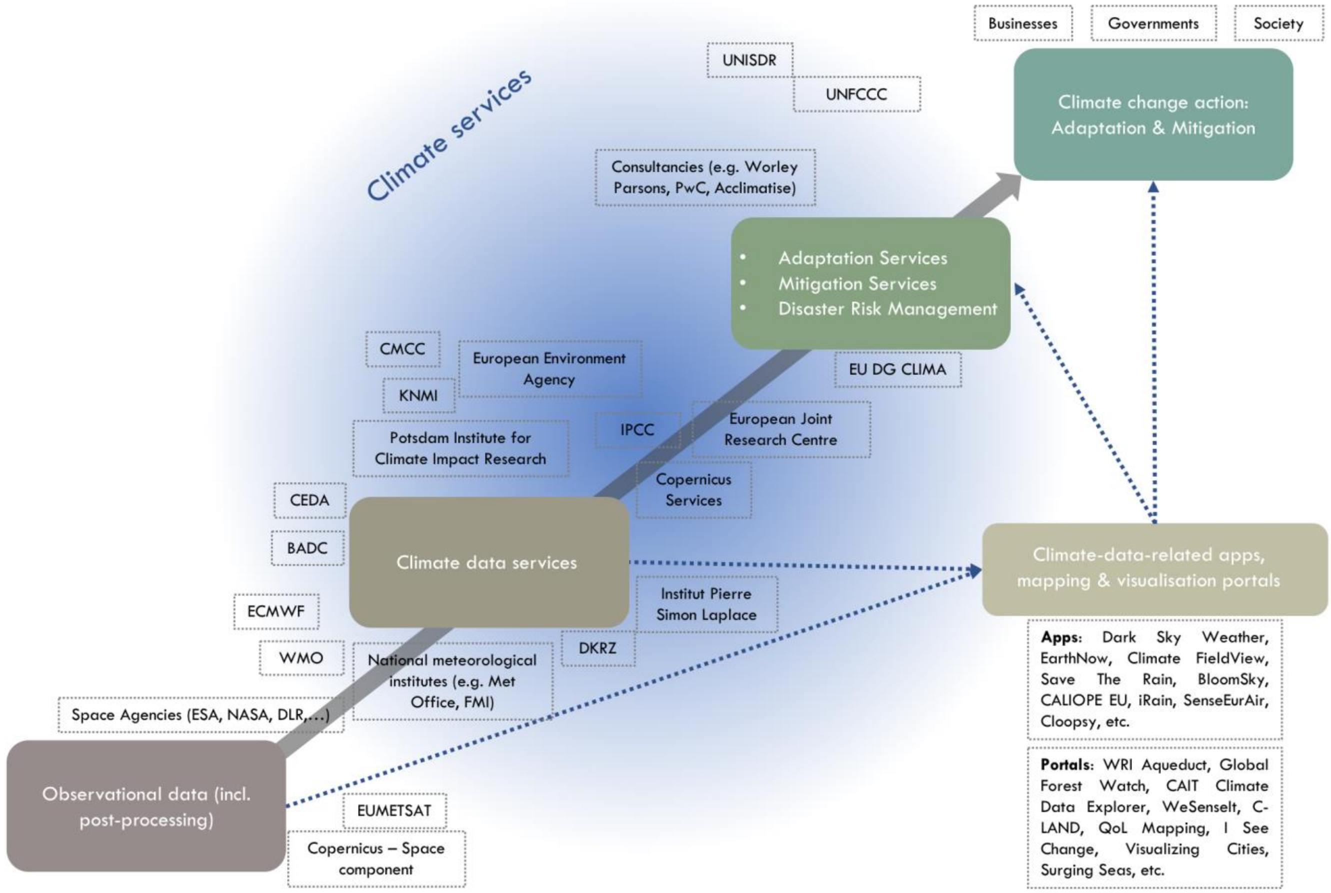
Figure 2. The logic behind these portals is often based on a simple logic: an organisation collects large amounts of data, a portal allows the user to access the data they need at their convenience

New portals are frequently launching. During the course of conducting this research, the Oasis Hub, an online portal/marketplace for the publishing and purchasing of environmental data, adaptation planning tools, models and services, was in pre-launch phase[7] and a new platform for open and free geospatial data, funded by the Bill & Melinda Gates Foundation and the Omidyar Network was also announced.

One commonly observed aspect of portals is that they often assume users have the expertise and understanding to know exactly they want, and the user is not often consulted, leaving their actual needs to be assumed. The strong reliance on portals is what one expert termed as 'portal proliferation' (Int1-3). This is not to say portals should not be used going forward, as they are indeed a useful tool to many. Rather, the issue is there may already be an over saturation of similar portals – a situation of 'peak-portal' may have been reached (Int1-2; Int1-3). Sub-task 2 in this report carries out original research in and around the usability of climate services portals.

STANDARDS FOR SUPPORTING INFRASTRUCTURE

Data storage is worth highlighting here as it is part of the instrumentation infrastructure that interlinks with all clusters of



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[7] The Oasis Hub also provide a brokerage service that assists users to find appropriate CS providers or combinations of providers. As such, Oasis Hub goes beyond the typical platform data access service 'offering'.

Figure 2 and important problems around data storage remain to be solved. These could hinder the uptake of the climate services market in Europe by slowing the data's dissemination. Despite efforts such as the ESGF and the ENES, data formatting is not yet completely standardized within data storage, despite concerted efforts toward this, slowing the ease of moving and storing data at times (Int 1-1), for example (cf. sub-task 3 on 'data', 'rules', 'authority'). Also, the presence of data managers or gatekeepers is underfunded, who could help avoid formatting issues. Finally, the vast amounts of data produced and stored also need special storage and dissemination infrastructure, for example, one Sentinel-2 satellite alone produces about 400 Terabyte of data per year (Copernicus is set to have a total of six satellite missions and complements that data with data from 30 contributing missions) (Seifert 2013).

Sub-task 1 Case Studies

CASE STUDY – 1: TRACING END USERS INDICATES NOTABLE USE OF DATA BY BUSINESS SECTOR

Access to Copernicus data is open and free, but requires registration. This case study focuses on one aspect of the Copernicus service, namely the Belgian users of the Copernicus Marine Environment Monitoring Service (CMEMS). CMEMS is an easy to use platform (see sub-task 2, where its usability is ranked), used by many sectors. Tracing the end users of data, and for what purposes the data is being used is not common across platforms like these, though tracing these for CMEMS highlights important trends in the use of data. In this case: a notable number of users in the business sector who are growing the climate services market by commercialising the end product.

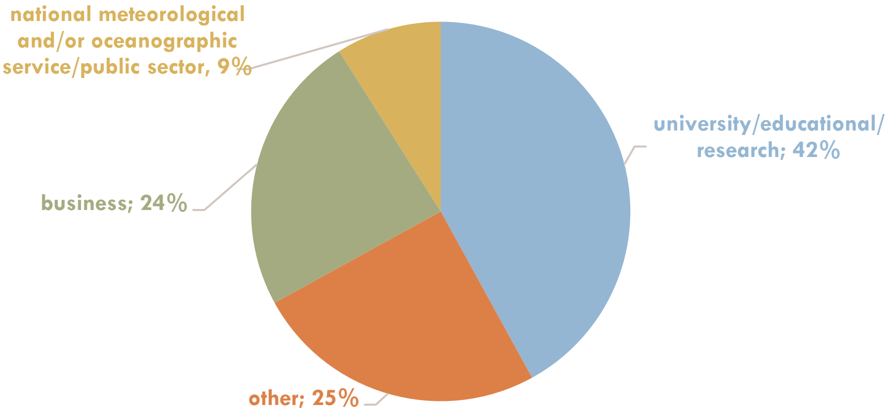


FIGURE 3: CMEMS USER MAKE-UP

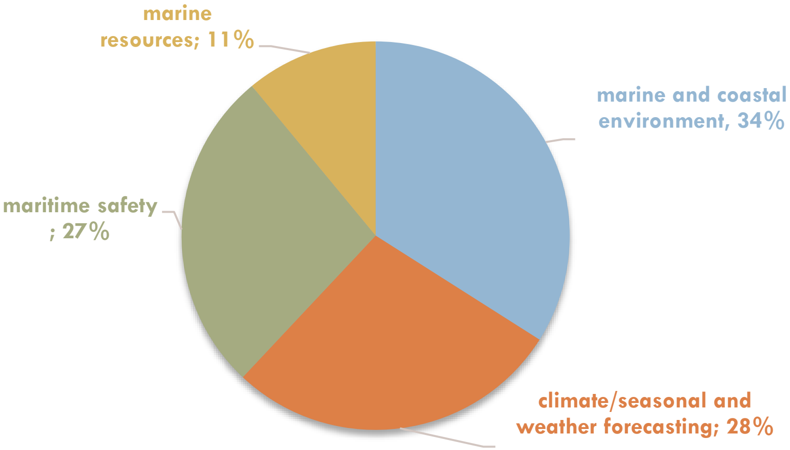
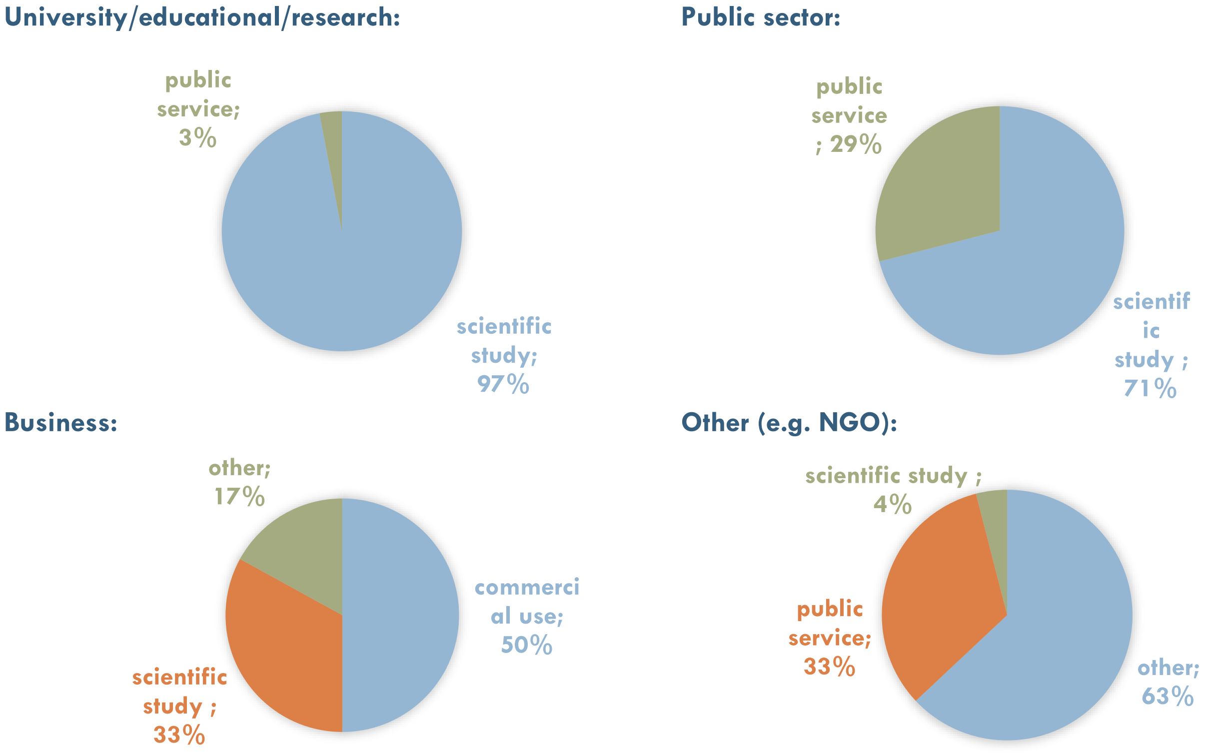


FIGURE 4: CMEMS USERS' AREAS OF WORK

Figure 3 indicates who the end users of the data are, by sector. Belgian users of CMEMS were found to be primarily in the university, educational, or research fields at 42 percent (European Commission 2016c).

These numbers indicate the most likely users of open and free data will be researchers who have the skills to work with largely unprocessed or only lightly processed data. This could also indicate data is used by those who often face budget constraints (Int 1-2), as the data is freely available for use. Figure 4 indicates that there is a fairly even distribution in the users' areas of work, with use on marine and coastal environmental studies being the highest at 34 percent.

Another notable end user is the business sector, at 24 percent. Figure 5 shows what the end uses of the data were found to be, with 50% of the registered businesses indicated using the data for 'commercial' purposes, though there is no further information as to the exact content of those commercial purposes.


University/educational/research:

Public sector:

Business:

Other (e.g. NGO):

FIGURE 5: END USES OF CMEMS DATA BY SECTOR

It is essential for climate services providers to be able to take into consideration their users' needs, as failing to do so prevents even the possibility of tailoring the products and functionalities of the sites. Tracing the end uses, as has been done here, allows for this and indicates what may not be obvious – that businesses also use the data alongside universities and research organisations. In keeping track of this, CMEMS is in a position to at least begin to remove a persistent barrier to the growth of the climate services market: not factoring in the user perspective. It is crucial for climate services providers to have this reflexive ability; taking stock of who is using what information is an important first step to expanding the climate services market.

CASE STUDY 2: MOBILE AND WEB-BASED APPLICATIONS

As can be seen in Figure 3, a large number of mobile and web-based applications (apps) are being developed that use observational data and/or climate data. While the data sources cannot always be identified, it seems safe to assume that especially small companies and start-ups developing apps can profit from access to free and open data.

The purposes of apps that use observational and climate data vary widely. Some operate as simple data visualisation tools, such as NASA's EarthNow, which offers "visualizations of near-real-time global climate data from NASA's fleet of Earth science satellites" (NASA 2012). Others have more specific functions, like EOMAP's eoApp, a high-resolution inland water quality monitoring service based on satellite data, which also uses Sentinel-2 satellite data – one of the Copernicus satellites (EOMAP 2014). Future Everything and the Barcelona Supercomputing Centre created an app for the European research project EUPORIAS named Ukko (EUPORIAS n.d.; Project UKKO n.d.). The app is an interactive interface for the wind industry through which users can explore probabilistic wind speed predictions.

In addition to these apps, which are all available free of charge, businesses are developing climate data related apps and tools on a commercial basis. For example, the Dutch company Miramap offers an app called Droughtscan that allows users to map underground soil moisture variations (Miramap 2017). To achieve this, the app uses satellite data to monitor weather and climatic conditions that influence soil moisture. Another example is Acclimatise's Aware™, an online climate risk screening tool to identify and understand climate risks to projects (Acclimatise 2017). The tool uses climate model outputs, observed natural hazard data, and data about current and future water scarcity that have been post-processed for use within the tool.

There are also apps being developed with observational and climate data that do not fall entirely into the climate services field because their aims are not climate-related. However, they offer interesting examples in which these data are being used creatively for other purposes. For instance, CMEMS data is being used by a French start-up called *SailGrib*. Their app of the same name provides sailing routes based on CMEMS and boat-specific data (SailGrib 2017). Another Copernicus-related example is the app *SnapPlanet*, which lets users choose any location on Earth and 'snap' it. The app then provides Sentinel-2 satellite imagery and the user can post it on their account. *SnapPlanet* is described as 'earth observation social network' and won the ESA app challenge in the Copernicus Masters 2016 competition, where innovative EO-based solutions for business and society can win prizes (Copernicus Masters 2016).

Sub-task 1 Summary of Findings

BOUNDARIES ARE FLUID

The boundaries of the climate data service infrastructure are fluid. Actors, especially further upstream, do not exclusively stay in one segment of the infrastructure but provide downstream services and products based on undertaking additional processing and interpretational analysis. Researchers and personnel often move between these clusters of activity, as experts consulted for this research indicated they themselves have worked in various clusters shown in Figure 3 throughout their careers.

OPEN AND FREE ACCESS DATA IS A DOUBLE-EDGED SWORD

Open and free data can be both a barrier and an enabler. On the one hand, open and free climate data provided by e.g. Copernicus C3S can help organisations with budget restrictions develop their business. Conversely open and free data may also discourage the commercialisation opportunities by business potentially offering similar data products. Limiting access to data via a pay-wall is a large barrier to further uptake, though paradoxically there is an increasing realisaton that costs around data collection may need to be recovered (Int 1-3).

TRACKING USERS

Tracking users and uses of climate data can be difficult, if free and open data portals do not have required or mandatory registration process that records such information. In contrast, sites like ESA require extensive application processes for certain data sets. While time consuming registration processes with very detailed questions can be a barrier, they also allow the data provider to paint a more accurate picture of the user base.

PORTAL SATURATION

Peak-portal may have been reached. Although there is still much to be achieved in developing data access sites for specific user segments (e.g. the mining sector who have specific data needs) we may see increasingly diminishing returns in the value of launching more ‘general’ climate data portals.

MORE BUSINESSES ARE USING DATA TO DEVELOP PRODUCTS

While climate data is still predominantly used by universities and research facilities, there are many indications that private businesses are using climate data to develop products for profit. This could represent a shift from the proliferation of portals toward more user-driven dissemination channels.

APPLICATION AND VISUALISATION TOOLS

Mobile phone and tablet technologies are creating new opportunities for developers to kick start new climate services products and provide them to consumer markets quicker than ever before. This new paradigm will continue to shape the market and bring accessibility to a new ‘non-expert’ user segments comprising, for example, citizen scientists, private sector organisations and the public in general.

STANDARDISATION OF DATA INFRASTRUCTURE

Non-standardisation of key aspects of the data infrastructure could hinder the uptake of the climate services market in Europe. Data formatting is not yet completely standardised within data storage, despite concerted efforts toward this, slowing networking and innovation potential.

Sub-task 2: Surveying

Introduction

A survey was developed for sub-task 2, to generate insight into the usability of observational data websites and portals. This survey assesses the access to specific data products – a sample of portals providing access to satellite-based observational data. It does not cover important issues in the information and communication dimensions of the infrastructure such as data formats and data governance (please see sub-task 3). Nevertheless, this survey provides general insight into the health of the climate services market by highlighting the nature of conduits (portals and websites) on which climate services are offered for consumption. These sites and portals can be both part of the information and communication dimensions of the infrastructure, and importantly, they contribute to the services infrastructure. Easy and efficient access to observational climate data via these sites and portals plays an integral role in developing derived products and services from the climate data.

Methodology

Preparation for the survey included review of the CS actors database created in sub-task 1, and creating a further classification table (see Figure 6). The various websites and portals were grouped in categories based on the type(s) of data they provided: satellite (raw and refined), in-situ (raw and refined), forecasts, climate projections and models, mapping and analysis tools and secondary products. This classification allowed for the team to compare traits of these sites and portals, and narrow the focus of the survey.

Observational data (historical and current)				Forecasts	Climate Projections, Models	Mapping and analysis tools	Secondary products (e.g. case studies, reports)
Satellite/Remote Sensing with different processing levels		In-Situ with different processing levels					
Raw	Refined (maps, graphs, etc.)	Raw	Refined (maps, graphs, etc.)				

FIGURE 6: CLASSIFICATION SCHEME OF CLIMATE DATA WEBSITES AND PORTAL

For the survey itself, one type of portal or site was chosen to ensure comparability of the survey results: websites or portals that provided observational data sets from satellites. The decision to survey observational satellite data portals was taken for several reasons. Firstly, these portals are very popular at the moment, with new upstream portals released frequently (while researching this paper the Radiant Earth[8] portal was released, for example). Secondly, the European Commission is putting strong emphasis on its own satellite data as the foundation of the Copernicus programme (European Commission 2017). Thirdly, we avoided investigating portals that offered climate model outputs, like the Earth System Grid Federation (ESGF) portal or the European Climate Assessment & Dataset (ECA&D) portal because these are developed for users with very specific expertise and knowledge and were too complex to survey given the time and scope of this report. Surveying these climate model output-orientated portals, however, could make for another area of interesting research and assessment, especially given the expected growth trajectory of climate model datasets and analysis (Overpeck et al. 2011).

The survey consisted of 18-20 questions or indices (see Appendix 1). The questions/ indices were constructed based on literature on usability heuristics (Molich and Nielsen 1990; Nielsen 1994), and guidelines for user testing (US Department of Human Health Services 2013).

The survey itself was divided into two sections. The first half of the survey assessed the overall usability of the website, navigation scheme, features and functionality and the search function. The second part of the survey focused on data retrieval and was evaluated through a usability exercise.

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[8] A new platform to accelerate open earth imagery technologies, funded in part by the Bill & Melinda Gates Foundation. See: www.radiant.earth for more information.

For the first part of the survey, questions pertained to ease of finding data, available formats, supporting materials and guidance, and exportability/'downloadability' were also included. Questions were answered on a scale of 1 to 5 from strongly agree (5) to strongly disagree (1). Overall results were then added up, weighted on a 100-point scoring system and portals were ranked according to their score. Scores were also calculated for individual sections of the survey, i.e. data retrieval. Additional 'yes' or 'no' questions were asked about payment, public availability, and licensing; however, these questions did not factor into the final score. In total, the authors surveyed 16 websites. See

Table 3 for the list of websites and portals selected for review in this sub-task.

For the second part of the survey, a usability exercise was designed as an accompaniment to the survey, and was designed specifically for the evaluation of satellite-based data portals. The purpose of this task was to remove bias by ensuring that the survey was approached with the same goal in mind rather than disparately evaluating the website for different reasons. The usability exercise involved finding a “raw satellite dataset”, downloading it, and if possible importing it into a spreadsheet. The surveyor was not asked to do any data manipulation, only to locate and access the data set. The survey did not evaluate the data itself, but rather it evaluated the ability of users to navigate the websites/portals to find data sets. Observational climate data can be collected in-situ or from satellites. Most of the surveyed portals for this task offered satellite-based data, however some, e.g. NOAA (National Oceanographic and Atmospheric Association), also offered in-situ-based data.

TABLE 3: LIST OF SURVEYED WEBSITES

Organisation	Portal	Country /Region
1. NOAA National Centers for Environmental Information NCEI	www.ncdc.noaa.gov	USA
2. NOAA National Weather Service/Climate Prediction Center CPC	www.cpc.ncep.noaa.gov/products/precip/CWlink/	USA
3. European Space Agency ESA (free data sets)	https://earth.esa.int/web/guest/data-access	Europe
4. Sentinel Data Access Service SEDAS	http://sedas.satapps.org	Europe
5. Copernicus Open Access Hub SciHub	https://scihub.copernicus.eu	Europe
6. EarthData NASA	https://earthdata.nasa.gov	USA
7. USGS Earth Explorer	https://earthexplorer.usgs.gov	USA
8. Indian geoplatform of ISRO	http://bhuvan.nrsc.gov.in/data/download/index.php	India
9. EUMETSAT	www.eumetsat.int/	Europe
10. Copernicus Marine Environment Monitoring Service MEMS	http://marine.copernicus.eu	Europe
11. Copernicus Land Monitoring Service LMS	http://land.copernicus.eu	Europe
12. Copernicus Atmosphere Monitoring Service AMS	https://atmosphere.copernicus.eu	Europe
13. GIOVANNI NASA	https://giovanni.sci.gsfc.nasa.gov/giovanni/	USA
14. DLR (German Space Agency)	www.dlr.de/eoc/en/desktopdefault.aspx/tabid-8799/	Germany
15. ECMWF	www.ecmwf.int/en/forecasts/datasets	Europe
16. UK Met Office	www.metoffice.gov.uk/services/data-provision/big-data-drive/wholesale	UK

Results and Discussion

Of the 16 surveyed websites, two required purchasing data products (UK Met Office, ECMWF) and one had a very complicated registration process (EUMETSAT). As such, the second part of the survey could not be applied to them. The remaining 13 were scored using both parts of the survey. The majority of websites surveyed for usability scored 'moderate'. Several websites also scored 'good' and one website scored 'excellent' (see Figure 7). The following sections provide key overall findings from the surveys, supported by examples.

Eight questions in the survey related to data retrieval and their score was isolated to be able to compare performance based solely on the task of data retrieval (see Figure 8). Seven websites scored 'excellent' or 'good', four scored 'moderate', one scored 'poor' and one 'very poor'. Table 4 shows the summarised scores for the 13 fully surveyed websites. Only one, Copernicus Marine Environment Monitoring Service (CMEMS), scored excellent across both the general questions and the data retrieval questions. Other websites that stood out in terms of data retrieval were Giovanni NASA, Sentinel SEDAS, and NOAA CPC. Only one other website stood out due to its overall usability, provided by the European Space Agency. Case Study 3 (p. 37) details the reasons why the CMEMS website scored high across all categories.

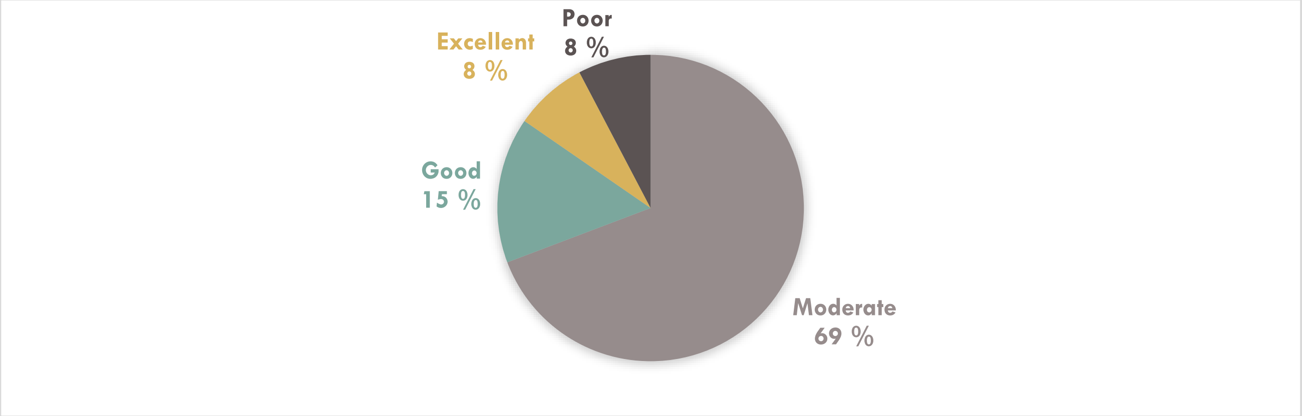


FIGURE 7: OVERALL USABILITY RANKING

Overall usability ranking indicated that 13 fully surveyed websites one scored 'poor', nine 'moderate', two 'good', and one scored 'excellent'.

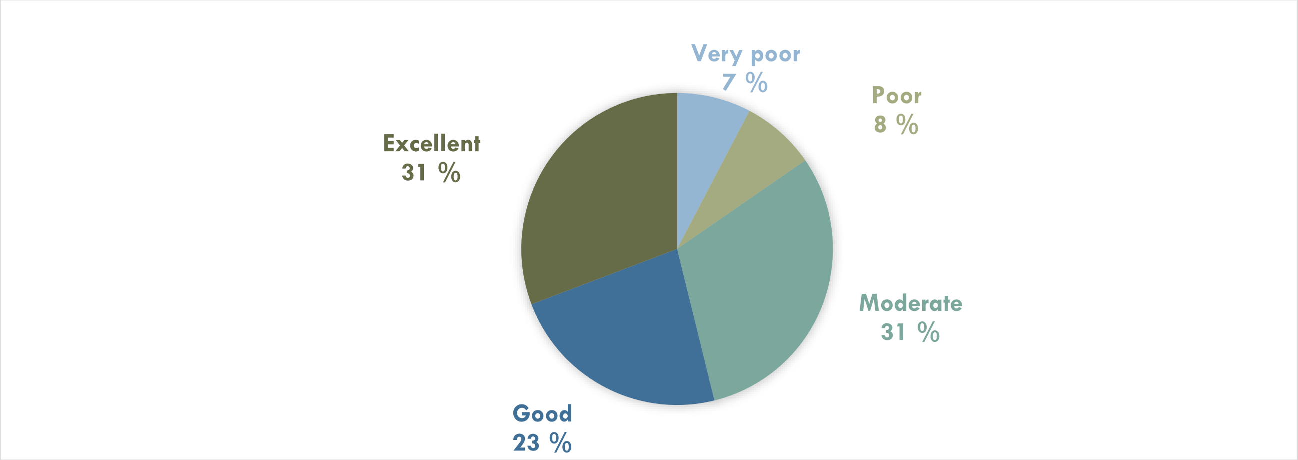


FIGURE 8: DATE RETRIEVAL RANKING

Part of the survey focused exclusively on the task of data retrieval. Websites received a score based on how straightforward it was to access a dataset. As shown above in Figure 8, four websites scored excellent (90-100%), three websites scored good (80-89%), four websites scored moderate (65-79%), one website scored poor (50-64%) and one website scored very poor (below 49%).

TABLE 4: SCORES OF SURVEYED WEBSITES

Portal	General score	Data score	Overall score
Copernicus MEMS	96%	100%	98%
Sentinel SEDAS	80%	91%	85%
Giovanni NASA	76%	90%	82%
USGS Earth Explorer	78%	80%	79%
EarthData NASA	76%	74%	76%
NOAA NCEI	82%	68%	76%
Copernicus LMS	66%	82%	73%
NOAA CPC	56%	90%	71%
ISRO Bhuvan	64%	80%	70%
EUMETSAT	64%	77%	69%
Copernicus AMS	70%	55%	68%
Copernicus SciHub	62%	74%	67%
European Space Agency (free data sets)	90%	28%	64%

Scoring percentages: 90-100% Excellent, 80-89% Good, 65-79% Moderate, 50-64% Poor, <49% Very Poor

Case study 3: Top scoring site - Copernicus Marine Environment Monitoring Service

Copernicus MEMS scored ‘excellent’ on the overall usability test, and on the data retrieval portion of the survey. The data was free, publicly available and openly licensed making it easily accessible to a range of users. The following points highlight the features that make the website highly useable:

- **The homepage is effective in directing and orienting users to the relevant information and tasks.** Users can quickly understand the website’s objective and can locate useful information in a few easy steps.
- **The catalogue and search features are straightforward.** Data sets are organized intuitively and the search feature generates relevant results. Datasets can be searched by location, e.g. ‘Baltic sea’ or by parameter e.g. ‘sea surface temperature’.
- **The website is catered to all levels of expertise.** The website does not alienate novice users through the use of technical terms and jargon, or a complex navigation structure.
- **Data retrieval is expedient.** Finding useful data is a quick and expedient process that can be achieved by browsing through the catalogue, and searching for data via the search function. There are no complex forms or registrations involved with data acquisition.
- Data was available in conventional file formats and easy to download.
- **Useful features and functionality.** Users can add data to their ‘shopping cart’ while they continue to browse data sets.
- Supporting materials (i.e. guidelines, case studies, FAQ) are relevant, useful and help enhance the users understanding of the data.
- **No bugs.** The websites performance did not inhibit the user experience. There were no slow page downloads, long delays or broken links.

Sub-task 2 Summary of Findings

SITES ARE NOT DESIGNED WITH THE USER IN MIND

The websites generally follow a ‘loading dock’ approach rather than a customer service approach. This means they do not appear to offer features that allow users to expediently access data sets of value and relevance, but rather host the data and present users with the task of having to *find* the data sets. In many cases finding data sets was a cumbersome task that involved numerous steps that could otherwise be minimised or avoided. For example, complex registration processes that involve numerous or complex questions are roadblocks that are a deterrent for users who wish for quick and expedient data access.

SITES AND PORTALS ARE NOT EASILY NAVIGATED

Most websites do not provide navigational schemes or search functions that support data discovery. If a user is generally searching for a climate variable and does have a specific data set in mind, the process of data retrieval is likely to be cumbersome or even prohibitively complex.

Navigation scheme: Several websites presented complex navigational schemes that were not intuitive and inconsistent. On several websites, the site maps were confusing and did not (directly) lead to areas where data could be accessed. Further, it was easy to get lost within the pages on the website.

Search function: most of the websites offered search functions, however they did not always generate relevant results.

SITES AND PORTALS ASSUME A HIGH LEVEL OF EXISTING KNOWLEDGE

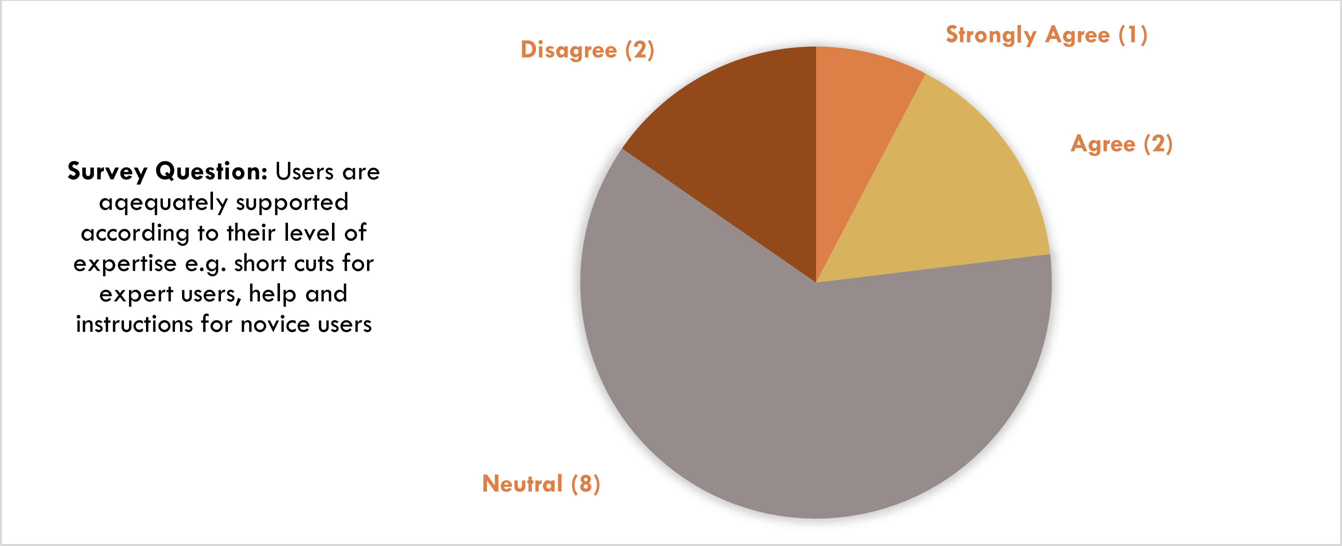
The level of knowledge that these websites presuppose of users is generally very high, which suggests that the portals are not designed with a lay user in mind. There was a strong tendency for websites to be catered to an expert user base and not to novice users or those who did not have a clear objective of what they were looking for or how to find it. This is shown through the organisation of information, the use of jargon and supporting materials that are catered to an expert audience. One needs to be an expert, or at least an experienced user to access data. Non-proficient data users will have a challenging time locating specific data sets, and understanding how they can be used.

Organisation of information: In several instances in order to retrieve data, users are prompted to search by satellite mission or instruments. This assumes that the users' knowledge goes beyond the climate parameters that they are searching for. This search prompt is likely to exceed the knowledge of a novice user and maybe even that of many professionals.

Jargon: Abbreviations and technical terms are used frequently throughout the websites. The use of jargon alienates the layperson (as well as perhaps experts from related fields) and suggests that the website is catered to a highly technical user group.

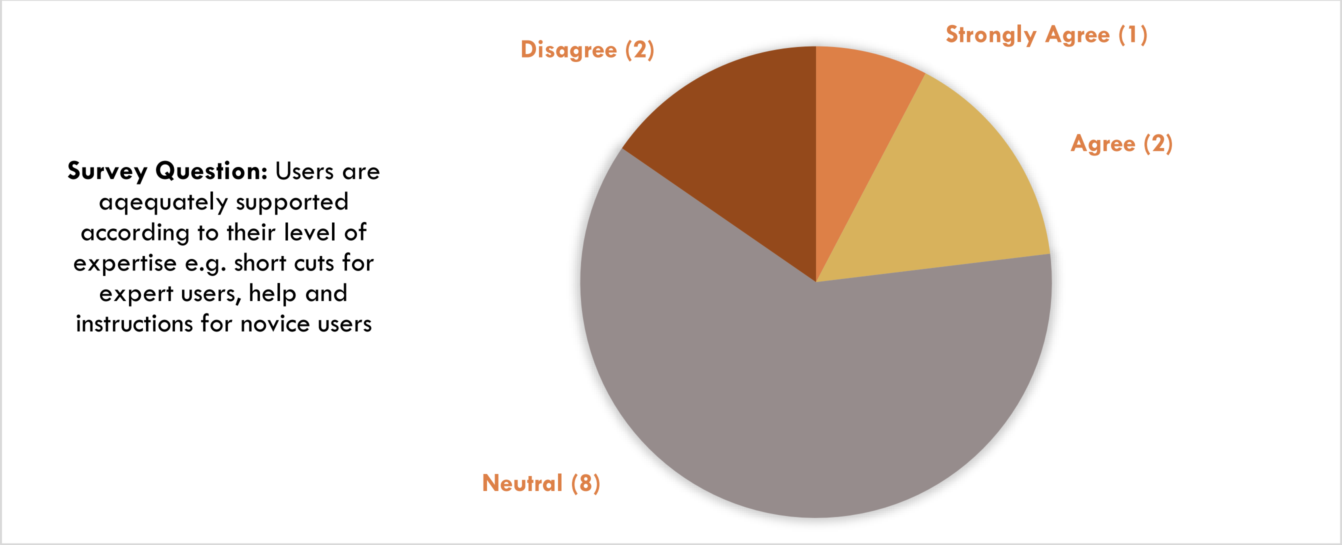
Supporting materials, including guidance, are generally available on all the websites, however they are written in technical terms and assume a high level of pre-existing knowledge. These guides are therefore catered to an experienced audience and do not support the non-experts in understanding how to use the data.

IT IS IMPORTANT TO NOTE THAT THIS SURVEY DID NOT EVALUATE THE USER'S ABILITY TO USER'S ABILITY TO *ACCESS* THESE DATA. THE LOGIC BEHIND THIS WAS THAT NO MATTER HOW DATASETS ARE TO USE, ACCESSING THESE DATA SHOULD NOT BE UNNECESSARILY COMPLEX. FIGURE 9



Survey Question: Users are aqequately supported according to their level of expertise e.g. short cuts for expert users, help and instructions for novice users

shows the results of one of the survey questions used for this study, asking about the level to which users are supported on each website according to their level of expertise. Less than a quarter of the websites had good scores while most were in the middle of the spectrum with lots of room for improvement. Two offered no support.



Survey Question: Users are aqequately supported according to their level of expertise e.g. short cuts for expert users, help and instructions for novice users

FIGURE 9: NUMBER OF WEBSITES OFFERING SUPPORT BASED ON USER'S EXPERIENCE LEVEL

PAYMENT FOR SERVICES IS A BARRIER TO USE

Most websites surveyed were publicly accessible and free. However, two websites could not be tested because they required payment for services, which fell outside the scope of the budget. These websites may be easy to use however they are likely to detract experimental, novice users or those with limited budgets by virtue of cost/payment. Interviews conducted with reinsurance professionals show that even amongst big multi-national corporations acquiring money to pay for climate and weather data can be prohibitive (NOAA and NCEI 2016). While this report does not intend to advocate for a free and open model, it should be recognized that payment for service is a barrier to use.

MORE PORTALS DOES NOT INCREASE USER UPTAKE

The survey focused on a few observational data portals from very large and international organisations. However, more portals do exist and even more were announced or launched while work on this report was being carried out. While the provision of access to observational data is a desirable aim, the sheer amount of options to access it becomes almost confusing, especially when several portals carry, for example, the same observational data from the same satellite missions. Some confusion could be avoided by having clear statements on each portal regarding intended user groups and explaining overlaps with other portals.

THE ABSENCE OF STANDARDS DECREASES USABILITY

If someone wants to shop online, be it clothes, electronics, or even groceries, they can do so across platforms without having to familiarise themselves with each new platform they access – online shops follow certain standards and a certain logic that has become recognisable and understandable for most people. However, the surveyed portals rarely had any resemblances in the way they were organised and required a certain time for the surveyors to familiarise themselves with the portals.

Subtask 3: A theoretical exploration of Data Infrastructure governance

Governance addresses the establishing, maintaining, changing, and occasionally de-aligning of social and political order, based on the interaction of all kinds of actors (also beyond the political system as such). Applied to climate data infrastructure, this means the governance perspective focuses on institutional patterns in terms of rules, standards, conventions of handling climate data with the related institutional routines and procedures, as well as with respect to the institutional arrangements and architecture that have been built to govern the data infrastructure in terms of the interaction order which reproduces or changes this infrastructure through an ongoing process. From this four infrastructure dimensions (instrumentation, information, communication, service) have been derived (see Figure 11).

Three major dimensions of climate services-related governance can be distinguished:

(1) **Framework Governance:** The EU framework governance that establishes initiatives to promote climate services alongside national governance is crucial for the provision of useable data and derived products in nationally specific contexts (including language);

(2) **European Climate Services Governance:** The governance attempt to develop the European climate services landscape further; and

(3) **Climate Services Data Governance:** The governance efforts dedicated to shape a more coherent "data infrastructure" within the complex set of institutions, conventions and practices in climate data gathering and processing. This involves agencies across Europe and in relation to other international and global initiatives.

Taken together, these three dimensions can be seen as **a nested bundle of governance actions** with interrelations that affect all three dimensions. The following section expands of the third dimension of governance described above, as it relates most closely to the intended scope of this research. The exploration is empirically grounded (through undertaking several interviews and the review of relevant policy documents). Then, the findings were framed from an 'interactionist governance studies' point of view (Colebatch 2009; Kingdon 2011).

Climate Services Data Governance

The governance of climate services data falls within a **specific architecture** in sharing a common goal. At this level of governance, the goal is to establish and maintain a structure and rationale for the data, the datasets, the archives and data curation. Governance is not just static structure, but also process.

A **service activity** is seen here as "*an operation intended to bring about a change of state in a reality C that is owned or used by consumer B, the change being effected by service provider A at the request of B, and in many cases in collaboration with him/her, but without leading to the production of a good that can circulate in the economy independently of medium C*" (See Figure 10, (Evenson and Dubberly 2010; Gadrey 2002)). Definitions of services are endless, and there is no consensus. Therefore, the one chosen here comes close to what we experience as typical features of a climate services market.

Services can materialise in **products** that are more than situated activity; services as things to be taken home (to a public or private body, or even by an individual citizen, manager or politician), implemented, refined or used further "at home" and perhaps even materially shared with other users there.

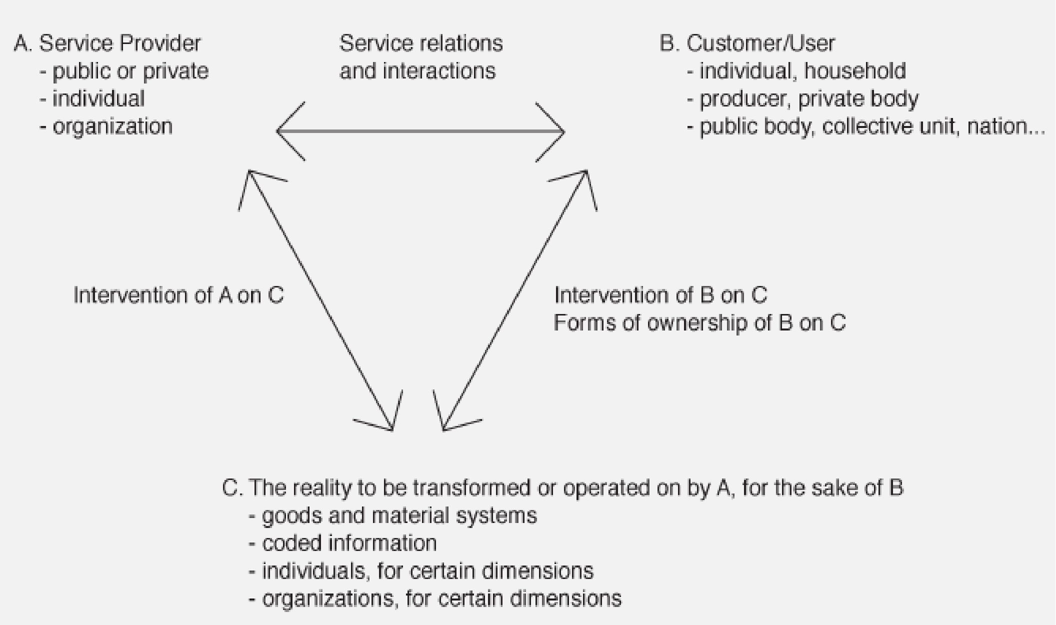


FIGURE 10: GADREY'S SERVICES TRIANGLE

Services can be offered, requested, provided and used – they are a give-and-take-relationship. The **quality and fit of a service** depend substantially on whether there is anybody on the user side that can engage in communication about data. When considering a service market, we look at a situation, in which all actors "*pursue their own interests and to this end perform economic calculations, which can be seen as an operation of optimization and/or maximization; … the agents generally have divergent interests, which lead them to engage in … transactions which resolve the conflict by defining a price" or a contract*" (Callon 1998, 3).

It is of utmost importance to view the climate services infrastructure set-up as one in which users already have their place, instead of being taken as "external factors" to a somewhat closed system. Precisely here, we argue, **success or failure of climate services** will be determined: in our ability to view and practically embed users as integral and equal partners in the co-construction of climate services - be it direct collaboration in the development of services or indirectly connected to service just on the basis of "good contacts" and mutual willingness to interact. In this sense, customers should hardly be considered simply as "outsiders", and if, only in terms of climate expertise, but certainly not in terms of their specific interests and usages for climate data. Involving users, however, might not guarantee success. It is a prerequisite of providing services that take users' demands into account.

Service provision in a knowledge-intensive economy is a **question of knowledge** (Hipp and Grupp 2005): about technologies, actors, successful and failing enactments of services, markets, boundary objects (services, tools, products, problems, information, etc. that allow potential interaction between otherwise disconnected areas and actors in the potential Climate Services market), and ways to mediate between those who could potentially form linkages in an emerging climate services market. Note: Market here refers to both activities in both commercial and public spheres.

The climate services infrastructures governance interaction order

For what follows, the leading question is **how climate data is bound into interaction between various actors and things**. Furthermore, when *data* is used, actors need knowledge on how to use the data, how to read the data, how to link it to problems to create new insights – and thus, data becomes *information* (data charged with knowledge about what it means) and it will be *communicated*.

For tackling the problem of data governance, several barriers can be identified from a governance point of view that, for the time being, make market interaction appear still rather difficult. Analytically, this is addressed by focusing on the governance of the 'climate service interaction order'. As structuring attempt, a sequence of characteristics is carved out that during literature review, analysis of policy documents, and interviewing turned out to be crucial; it follows a demand oriented logic, and it needs to be presented here stepwise, while in reality, it would rather be a set of intersecting and related characteristics during climate service negotiation (the latter notion to be understood as a general term for goal aiming interaction).

When considering the term '**interaction order**', it refers to the conceptions of infrastructure, service, and market as sets of activities within institutionalised and organised frameworks. With interaction, we mean "*that which uniquely transpires social situations, that is, environments in which two or more individuals are … in one another's response presence*" (Goffman 1983, 2). It is taken into focus since it can be presumed "*that the contained elements fit together more closely than with elements beyond the order; that exploring relations between orders is critical, a subject matter in its own right, and that such an inquiry presupposes a delineation of the several social orders in the first place; that isolating the interaction order provides a means and a reason to examine diverse*" social activities and structures comparatively (Goffman 1983, 2).

When considering the term **'order'**, it refers to a domain of activity (no matter how orderly such activity ordinarily is, in the first instance). However, on closer inspection, the "*workings of the interaction order can easily be viewed as the consequences of systems of enabling conventions, in the sense of the ground rules for a game, the provisions of a traffic code or the rules of syntax of a language*" (Goffman 1983, 5), thus also referring to broader social contract and consensus[9]. In deviation from Goffman (c.f. Bowker and Star 1999; Fine 2012; Mouzelis 2014), direct physical as well as technologically mediated multi-local co-presence is included in this notion of interaction order, in order to do justice to more recent developments in Internet-based interaction, computerised facilities to encounter social situations, and with respect to language that includes computer code. This order can be political, but it can also be market induced, thus we are working here with a very open notion of 'governance' which doesn't limit itself to government intervention, but rather included bottom-up emerging orders of climate services infrastructures.

These are our findings regarding the governance of climate services infrastructures. The findings are presented along the line of an "imagined service journey" (cf. the journey map in NASA, NOA and OSTP 2016: 9) starting from demand articulated by users:

1) The order of climate service **demand**: it all begins and ends with what the user needs, questions and concerns are (c.f. Int 1-3, 163:2). Demand for climate services is also born out of legal obligations, e.g.

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[9] "*As part of this perspective one could press two accounts. First, the dogma that the overall effect of a given set of conventions is that all participants pay a small price and obtain a large convenience, the notion being that any convention that facilitates coordination would do, so long as everyone could be induced to uphold it-the several conventions in themselves having no intrinsic value. (That, of course, is how one defines "conventions" in the first place). On the second account, orderly interaction is seen as a product of normative consensus, the traditional sociological view that individuals unthinkingly take for granted rules they nonetheless feel are intrinsically just. Incidentally, both of these perspectives assume that the constraints which apply to others apply to oneself also, that other selves take the same view regarding constraints on their behavior, and that everyone understands that this self-submission obtains*" (Goffman 1983: 5).

to account for climate change effects in urban and infrastructure planning;

a. In addition, then is to ask, **how demand for climate services is articulated**, and is there any opportunity for demand and service provision to become connected, and if, how? Demand can be translated into "what are you trying to achieve" and "what are the information requirements" (cf. Int 1-3; 163:2). There is a great diversity of providers and users. Demand, its articulation and its interpretation by providers is also diverse.

b. We distinguish four main types of **impulses to make use of climate services**, being (EU-MACS Consortium 2016, 13):

   I. **Legal obligations** might increasingly explicitly specify that information on climate risks should be integrated in decision making or practices (such as in urban planning and permitting)

   II. Implied motivations owing to market led or legislative **accountability for damage and/or malfunctioning** (such as failure minimisation in networks)

   III. Proactive **opportunity seeking** (such as creating sales advantages with new construction solutions) and expectations raised about socio-economic benefits of weather and climate services (Perrels et al. 2013).

   IV. **Science and curiosity**; here, it is not risk management, but scientific interest in the use of climate services directly or indirectly motivated by questions pertaining to risk management

   V. **Mass media attention** is often initiated by extreme weather events. Although, it is difficult to measure how much direct or indirect action follows from such attention, mass media plays a part in creating demand, for much of what we know, we know through the media (Luhmann 1996; Oudshoorn and Pinch 2003, 13) and the world wide map (Rogers and Marres 2000). Still, fundamental knowledge is indispensable when it comes to the interpretation of data or of specialised indices (Scott, Lemieux, and Malone 2011, 118).

c. Demand needs to be seen in context: "*Analysts need climate-change data tailored to their location and context*" (NASA, NOAA, and OSTP 2016, 4). Legislation can help to create demand for climate services, but this is by no means the only driver, as the previous four drivers indicate: all kinds of utility rationales are at work. This ties in with observations on **public-private cooperation** in data sharing (Klievink and Janssen 2014).

d. The use of climate services is expected to engender activities that will further stimulate the demand for climate services for reasons contained in the above categories ii to iv. This means that the widespread use of climate services feed into a **learning and transformation process**, partially stimulated by governance and partially stimulating governance to act with "climate intelligence" (EU-MACS Consortium 2016, 13).

Key points – the order of climate service demand:

Demand for climate services is expected to spring from a broad spectrum of institutional motives. Furthermore, it might indirectly be triggered also by mass media attention and from positive user experience. Thus, demand needs to be seen in context, and the service philosophy needs to be sensitive to demand and its context.

2) The order of **generating** climate data:

   a. There is a broad variety of **equipment** and **engagement** necessary for generating climate data, and the equipment needs funding, research and political will. The infrastructure of instrumentation is huge and the science of using it highly specialised; engineering is needed to improve hardware and software; the fact that there is already significant activity and funding in earth observation is based on deliberate ecosystem observation politics giving it priority. As such, there is a framework governance influence on the generation of data e.g. the current US government rejects the idea of climate change observation by denying climate change, or smaller or poorer countries without their own access to earth observation facilities may lack the capacities and capabilities create their own climate intelligence.

   b. Services will be using **existing** data as well as **generating** new data tailored for a specific user need. Existing data may be used for generating new data: "*For example, a city might provide the last 30 years' worth of data collected at their weather station's rain gauge — data a science translator can use to help frame the current climate-change situation. In other instances, the city gathers operational data to compare with climate projections — for example, municipal planners might compare their log of street flooding complaints with historical rain data to determine when rain starts to cause complaints. Local data becomes an input to climate-model downscaling. One city used their rain gauge data to help a precipitation projection better account for their microclimate.*" (NASA, NOAA, and OSTP 2016, 12). Of course, in municipal policy-making, many more factors come into play (such as influential interest groups like shop owners or neighbourhood activists, the receptiveness of a municipality for climate-related intelligence, etc.); however, this example also perhaps shows a possible direction for urban administration and planning.

   c. In addition, we know (European Commission 2015, 3; Nightingale et al. 2015, 11; Street 2016, 3) that users need to **link climate data to various other data** (economic, geographical, historical, medical, etc.), and thereby create new information in which climate data are only one aspect. This means not only scientific vs. other **rationalities** may clash or have to learn to link up, but also inner scientific, interdisciplinary gaps need to be overcome, as well as distinct logics of different professions. Only if there is capacity, will, and capability, the **communication** can take place and meaningful climate intelligence be developed. Linking to other datasets, however, does raise important challenges for data management, conventions, and quality insurance.

   d. Generating data is technically and cognitively linked to the task of data registration by unique identifiers, ideally by assigning a 'Digital Object Identifier' (DOI) through a registration agency (CNR-ISTI 2012, 50–52). For this, a data registration instance must first be created and empowered.

Key points – the order of generating climate data:

Existing and new equipment (instrumentation, including software), meaningful data (information infrastructure), as well as engagement (communication infrastructure) together leads to generating "data for climate services" – it is not limited to some uncommented raw data or a portal without human support alone.

3) The order of the **data**: related to the aforementioned points, **heterogeneity** is another other big barrier for wide take up and usage – subtle differences are enough to make automations difficult (see sub-tasks 1 and 2 above result regarding absence of standards).

   a. **Data curation:** "*the activity of managing the use of data from its point of creation, to ensure it is fit for contemporary purpose and available for discovery and re-use*", at higher levels "*maintaining links annotation and other published materials*" (CNR-ISTI 2012, 31); or as a practitioner at CEDA put it: "*… we mean proper data management practices. So, making sure that we preserve the bits and bytes properly in the datasets so that they will be accessible in future as well as now. Making sure that we properly catalogue our datasets so that we have appropriate metadata to describe who did it, what they did, why they did it, where and how they did it, and so that involves discussions about data formats and data standards*" (Int1-1; 160:8). The 'Infrastructure for Spatial Information in Europe' (INSPIRE), in implementation since 2007, could serve as a good practice example.[10]

   b. **Harmonisation:** institutes develop a culture of standardising data within their depositories and using a few, specific standards for the software with which they process the data, at the same time free software and broadly available, thereby reaching some level of economy of scale and a less need of personnel for data curation: "*we centralise all the data that we use in a single depository. So, all the members of the departments access the same data depository regardless of which a simulation or even observational data is being accessed. So, we use the same standards in terms of the file format and meta-data, for the air quality work, for the climate work, for the observations. Then, people access the data all in the same way. So, people who are working with the agricultural sector, access the data in the same way and the same place as those working on air quality. That allows us to have only a couple of data managers that can give service to everyone. When we run simulations ourselves, the model is exactly the same one for everyone, as well, because it's centralised and made available under our vision control system. We use Git for this. ... this is just a tool that allows you to control which version of a software that you're interested in you're using and it also allows you to document that software. The other commonality is the software and the solutions that we use for the development of the basically the solutions for the applications. So, we always use freeware, […] software that is available in the public domain. And, we only develop things that use Python or Bash. That also allows us to have just a few software engineers that can give service to all the people, for instance, working in the services group. All these commonalities, which are shared by all the groups, will allows us to do some economics of scale.*" (Int 1-2; 162). Thus, efficient harmonisation goes beyond the own stock of data, including also linking up to a broader community of data and software users.

   c. **Formatting issues:** For the CMIP5 NetCDF files, for instance, the assumption was "*if I can talk to one, I can talk to all*" – but the code doesn't work equally **across the file format,** for there are discrepancies at different levels. There is no "consistent tool" yet in sight for the huge data warehouse. (Int1-1; 160:37). Experts report on data collected (in the UK, by the Met office) it is "horribly formatted"; for example, "*if you wanted to obtain X for one area, you have to download the files for all of the UK for that time period*" (Int1-3; 163:14)

   d. Climate services data infrastructure assumes the need of a **broker service** which can ingest

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[10] "The INSPIRE Directive aims to create a European Union spatial data infrastructure for the purposes of EU environmental policies and policies or activities which may have an impact on the environment. This European Spatial Data Infrastructure will enable the sharing of environmental spatial information among public sector organisations, facilitate public access to spatial information across Europe and assist in policy-making across boundaries."

externally received data feeds into data catalogues. Brokers would also assist users downloading or processing data from providers (Busswell and Pradhan 2015, 14).

e. As a principle of product, the credibility of data inputs could be checked; for this, it has been suggested to add context information to data sets, or even to introduce a barcode that helps tracing the source (Int1-3; 163:8).

Key points – the order of the data:

Data itself needs to be adapted for use and service (information infrastructure). This task extends from formatting to brokering in order to become accessible (see right below on 'access').

4) The order of **access**: one of the first hurdles with climate information currently is 'What is there?'

a. **Support** is often required by users when it comes to accessing climate data and understanding what type of data exists. "*'Finding aids' are tools that help users find the most appropriate datasets, and enhance inclusiveness by helping users across roles, locations, and levels of adeptness*" (NASA, NOAA, and OSTP 2016, 28). However, other data sources may indeed provide somewhat easier to grasp accounts on major climate developments.[11]

b. **Findability** is seen crucial for "*searching for data/information/knowledge, tools and services*" (CNR-ISTI 2012, 48). Related to this issue, a paradigm shift is underway. Typically, a "*search is conducted without taking into account such context as professional profiles, work goals, data provenance*", whereas now there is an emergence of a situation where "*relevant aspects of data attributes, tools/services functionality and deployability, context, provenance, researcher profile and goals, etc.*" are becoming increasingly common (CNR-ISTI 2012, 48).

I. Key to findability is the "*capability to quickly and accurately identify and find data that supports … requirements*" (CNR-ISTI 2012, 56): **data discovery**, which includes data classification, dictionary, metadata registry, inventory.

II. The same is true for **tool/service discovery** (including tool/service description, registration, and mediation support along the process of using) (CNR-ISTI 2012, 56-62). This echoes the above sub-task 1 findings about how underdeveloped applications and visualisation tools are.

III. **Data sharing:** openness to exchange results of work within a community is only one aspect of this task. Depositing or making them available through suitable channels within the community of climate data-related organisations is another task that needs strategy, contacts, efforts to document the data and virtual places to share. Barriers are the willingness to share (since data counts for those who made them, if not in monetary ways, then in terms of reputation), locating shared data (finding out where they are), and using shared data (availability, access, knowledge about where the data comes from and how to use it according to data features and

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[11] C.f. ECA&D (portal to visualise and provide all kind of climate indices, trends, climatologies based on daily time series, also for stations that are not freely available), Climate Explorer (portal that gives access to many observational and model data; developed for climate scientists, but with some short explanation lay persons can also use parts of it), CLIPC and Climate4impact (portals for people with various levels of expertise that provide access to data and tools for visualizing/processing; in the background ADAGUC is used), IMPACT2C (portal with impact information).

properties) (CNR-ISTI 2012, 68-69). Normally, one would expect a barrier to be an unwillingness to share. However, it is important also to see that it cannot be assumed sharing to be in everybody's immediate interest.

Key points – the order of access to climate data:

Access and findability depend on a combination of appropriate tools, incentives, and services for discovering and sharing data. This is the case not only at the end of the value chain, but from the outset, essentially for everybody trying to access and use the data at any stage.

5) The order of the **rules**: this refers to the core issue already found with regards to missing standardisation of climate services data infrastructures at the organisations and applications levels identified in sub-tasks 1 and 2:

   a. **Practicalities** related to these challenges have been expressed in the expert interviews; some examples may shed light on the scope and depth of these issues:

      I. **Limited building of conventions:** CMIP6 is emerging at the moment and trying to do things better e.g. improving naming conventions. If a file has TASMIN in it, users understand that it contains "temperature surface minimum" data. However, that is not enough. Systems and standards are needed that look at all the characteristics of the variable e.g. at what distance from the surface was the temperature recorded? (Int1-1; 160:3)

      II. **Institutional stability**: in the long run, stability depends on "*establishing and maintaining networks that include information producers and users who can continually interact to refine and revise the necessary information*" (Meadow et al. 2016, 13)[12] and tools. This non-static stability approach would institutionalise quality control and co-production, while allowing to continuously answer to change.

   b. The GRDI 2020 report states, "*infrastructural services must make the holdings of the components of a digital science ecosystem findable, agreeable and interoperable*" (CNR-ISTI 2012: 48). Conventions and practical rules are thus needed to structure such a data ecosystem in a reliable manner. Currently, there still is, for instance, **a lack of a universal standard for citing** quantitative data; a minimal citation standard is under discussion (CNR-ISTI 2012, 52), including a 'unique global identifier', a 'Universal Numeric Fingerprint' (UNF), as well as beyond the technical also institutional and actors'/users' commitment (CNR-ISTI 2012, 52).

   c. Data formats are rules about how to form and communicate datasets. They are also about how to use them and who defines the formats by which users communicate and use data. For example, the Climate Change Center Austria (CCCA) most frequently uses formats such as NetCDF, WMS, XML, PDF, ZIP, XLSX, RDF, tgz, CSV, wmts; and less frequently uses: grid, XLS, TXT, SHP, KML, GeoJSON (CCCA Data Centre n.d.). As soon as other types of data are required and other users are involved, this picture may completely change. A CEDA representative however sees harmonization through CMIP6 emerging and improving naming conventions. While there is already some convergence in

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[12] We claim this is true also for all other systems, not only decision support systems, for it institutionalises revision and co-production of quality.

the types of data format used, there is **still no gold standard**, although NetCDF in CMIP6 often is the current standard used for climate model data (with some variations).

d. How do standards and conventions **emerge**? Through (a) repeated action that works, which first becomes routine and then is habitualised into a social institution - a pattern, a rule, commonly considered to be right (Berger and Luckmann 1966), (b) communication among members of a community sharing similar kinds of data, agreements, and technological aspects that inscribe themselves into an infrastructure practice for at least as long no one changes the technology (c.f. Pelizza and Kuhlmann 2017; Star and Ruhleder 1996); even methods (e.g. Neshati and Daim 2017) and institutions of normation (DIN, ISO; here recently CMIP5, 6, 7) have been installed to tackle this problem (Vollebergh and van der Werf 2014):

   I. For CMIP5, the community went through somewhat of a revolution in terms of **people talking to each other and defining standards** (structure, content, format of data files) – if data is standardised, it is easy to build software around it. Significant effort went into agreeing these standards, but the result was far from perfect. For CMIP5, it was agreed to use NetCDF, however, there were still discrepancies, like naming conventions for versions, and overriding of versions making it difficult to comprehend the evolution of datasets (Int1-1; 160:34);

   II. Standards are in disarray even in a regional context where data standards and conventions have not been clearly agreed. For instance, the Atmospheric Monitoring Facility agreed a few years ago to **review data formats**. This process still underway and is being implemented in a effort to bring the community together. It seems something like this is needed across the board (Int1-1; 160:35);

   III. There are practices and standards that govern individual standards in place. These **high-level standards** have the potential to be developed further, especially in terms of 'quality assessment' (QA; see Deliverable 1.2). Formalised procedures exist from WMO and ISO, whereby ISO 90001 could even play the role of a meta-QA (ensuring the QA of the QA, which is a question of QA and data infrastructure governance in terms of deliberately framing QA through governance). Formalised procedures could also benefit from user satisfaction measurement (as ex-post QA) and co-production of QA while involving users actively in climate services activities (as on-going quality negotiation process).

e. Information and communication technologies are omnipresent in climate data practice, technical codes and algorithms affect the forms of knowledge and directionality of innovation in the entire climate data area. In many ways technology governs, whilst at the same time there are policies and governance approaches inscribed into software, hardware, organisations and climate data technology: "*... code, protocols, software, and algorithms are not only technologies to be governed but also full-blown governances actors enacting regimes of inclusion/exclusion from innovation process*" (Pelizza and Kuhlmann 2017, 3). The opposite of inscription, description, occurs in cases of crisis or rupture: the inscribed rules and other patterns become visible and even negotiable (ibid, 8). Climate services would want to carefully consider whom they (implicitly/explicitly) allow to take part (or not), and how.

Key points – the order of rules:

Rules refer to standards and stable institutions. They help to understand what the data means. They emerge from practice. This needs specific attention. Transorganisional rules can only take shape and effect when interaction between organisations leads to standing practices. The same applies to different entities within one and the same organisation.

6) The order of **organisations**: **Building a climate services infrastructure** involves processes of institutional reordering with interoperability as a constitutive trait of any infrastructure (Pelizza 2016, 305) not as mere facilitating of inter-organisational relationships (ibid, 307). The meaning of what a 'National Meteorological Office' is, what a 'supercomputing center', or a 'City Environmental Office' will have to be redefined by data conventions, ports, depository policies, software codes, firewalls, ethics schemes, business models, etc. Similarly, the governance approaches of climate data generating and processing agencies affect various dimensions of infrastructure:

   a. The climate service enabling organisations as well as all the partners interacting with them have more or less explicit **policies for data infrastructures**. Where lacking or in case of policy gaps, policies can help achieve more structured behaviour within and among organisations, on technical as well as at the human and social levels of data infrastructure:

      I. **Policy-based network management** promises "*reusability, efficiency, extensibility, context-sensitivity, verifiability, support for both simple and sophisticated components, and reasoning about component behaviour*" (CNR-ISTI 2012, 90);

      II. **Policy specifications** help building a language framework, sub-domains, constraints, and can contribute to explaining ontologies the climate services data community wishes to establish and justify (CNR-ISTI 2012, 91);

      III. Policies foster "***security, privacy, authorisation, obligation** as descriptions in a machine understandable way*." (CNR-ISTI 2012, 90; bold text added here);

      IV. Policies help with **conflict detection and resolution**, allow for **policy enforcement**, and they can support managing **trust** (CNR-ISTI 2012, 92-94).

   b. Organisations facilitating and providing climate services data infrastructure need personnel that are able to bridge knowledge gaps and practice between providers and users, always depending on the type of service provided. They are, as data centres for instance, often serving various communities, like earth observation with lots of satellite data products, oceanic data, atmospheric data, data from weather observation – all linked to different user communities. What is needed could be called **intersectional or transdisciplinary competence**. Engineers could find it a risk for their scientific careers, and fear not being rewarded for a multi-disciplinary way of research (Int 1-2; 162: 14). However, plenty of practitioners in this space have in-deed successfully achieved transdisciplinary competence.

   c. Organisations in climate service need a **policy** that encourages and supports employment of new and further training of staff in terms of such translational capabilities. This can even mean more specific funding, enhanced networking with practitioners in other fields and the development of additional interdisciplinary journals in order to encourage personnel to work at the intersection with other technical fields, beyond their own.

d. In general, organisations providing climate data services might find it useful to take on the **role of intermediaries**: with a broadening scopes of tasks that allow them to develop closer interactions between demand and supply sides (Howells 2006; UNEP FI and SBI 2011, 51–52). Intermediaries in the climate services data infrastructure context have been defined as follows: "*People or organisations who work as intermediaries assisting stakeholders in decision making. They help them in specifying information requirements, applying information and sharing experience. They can also help to jointly generate new knowledge. Intermediaries are sometimes referred to as intermediaries or knowledge brokers. Organisations such as the EEA but also consultants, national environmental protection agencies, research institutes providing policy support, and managers of national and international climate and climate adaptation portals as well as facilitators of climate discussion fora can be considered 'intermediaries'*" (Groot et al. 2014, 12).

Key points – the order of organisations:

Building a climate services infrastructure involves processes of institutional reordering aiming at interoperability. This refers to technology as much as to personnel. Dedicated policies are needed. An organisational self-understanding as 'intermediary' is also constitutive.

7) The **order of authority** in the overall socio-technical regime, with respect to (a) data organisation and (b) inter-organisational collaboration:

a. **Data federation**: Since there is a broad range of decentralized data practices to which the notion of 'data federation' refers, several governance tasks for a next generation of climate services infrastructures at the data level are seen as essential:

I. **Data integration:** "*combining data residing at different sources, aiming at completeness and conciseness*" for users (CNR-ISTI 2012, 62);

II. **Data harmonisation:** "*the process of comparing similar conceptual and logical data" to determine the common, similar, and dissimilar data elements resulting in a unified data model that can be used consistently across organisational units*" and organisations (CNR-ISTI 2012, 62);

III. **Data linking:** "*the process of publishing data on a … data space in such a way that its meaning is explicitly defined*", linked to and from other external data sets (CNR-ISTI 2012, 62);

IV. **Gatekeeping function:** Organisations with gatekeeping tasks at the data centres will only partially play a role of requesting to comply with standards from data providers, because at the same time, when the data is useful and there is a chance others can find a way to use it, the gatekeepers would still allow it to be added it to the system (Int1-1; 160:38). Services prices remain high due to bad infrastructure coherence.

b. **Inter-organisational collaboration** on climate data:

I. **Lack of authority:** Flat hierarchies do not necessarily lead to anarchy, but they create challenges, such as a lack of leadership, where motivation or guidance is needed; less supervision can also lead to less consistency in practices, policies, products, and crisis reaction; decision-making in flat hierarchies can use the broader wisdom of all involved, whereas processes of decision-making can get (micro-politically) more complicated and lengthier. The ESGF, for instance, has a flat hierarchy where no one can exercise power over others. It is perceived as there are also lots of politics and tensions, search functions and web interfaces suffer from this (Int1-1; 160:2). The complaint in this quote is that in this case the commitment to harmonisation of conventions is underdeveloped. As such, the climate services data infrastructure market would profit from more standardisation, as well as from better, more intensive communication: "*actually, there are people all over the world doing bits and pieces and, what my perception is, a lot of it is quite inefficient because so much communication needs to happen in order for everyone to be on the same page*" (Int1-1; 160:28)

II. **Missing central standardisation agency:** More standardisation would require a third party organisation overseeing the conventions ruling in climate services infrastructures. ISO could possibly play that role (Int1-3; 163:8).

Key points – the order of authority:

Authority, effectively used in the context of building a climate services data infrastructure, helps to form a productive collective, able to solve conflicts where dysfunctional (lack of consistency) and stimulating them where functional (lack of commitment, compliance, innovation). Authority requires mandate, expertise and power. In service infrastructures, it needs to be shared with users/customers.

8) The order of **funding**:

a. **Influence of funding:** When we look at how infrastructure depends on funding policy, most organisations that could achieve data curation with broad impact are usually funded for an end-product. However, funding would be better placed at the 'invisible infrastructure' level, where it might become useful only in a couple of years, but this would build the critical capacity of getting to a functional system for data and information exchange (Int1-1; 160:40). Here, the need for funding for generic data management is expressed. There is a systematic lack of it due to output orientation in funding policy.

b. Instead, (EU and global) **project funding**, and thus financed collaborations, are merely used as a way to keep up with developments. In cases, this is even recommended as a clever way of using incentives by taking advantage of grant funding related to climate services (c.f. NASA, NOAA, and OSTP 2016, 11). The negative, and most likely unintended side-effects are, however, that e.g. EU projects are used as vehicle to keep in touch with ESGF instead of contributing to ESGF what would really lift the EU climate services basis up to a new level of quality (Int1-1; 160:41).

c. There are broadly two **models** for how climate services data infrastructure organisations are funded: by public money or by revenues from private businesses; mixed forms are not unusual (in terms of public-private partnerships on organisational level or in terms of using publically financed climate data for private business products). The question is unsolved as to how, under the prevailing market conditions, those who can't afford to pay for more sophisticated services are able to do so. Currently, the development of sophisticated services is often only feasible with expensive high resolution, combined sets of data, and provided only by for-profit organisations that are motivated to use climate data for competitive advantage. In this respect, the EU double strategy of achieving better mitigation and adaptation to climate change via market mechanisms could significantly underachieve expected outcomes, or get caught in a performative self-contradiction.

d. **Funding priorities:** Observers of funding policy say there is a tendency to prioritise top level and user level funding (see also above 6. b) and 8. a)). For a realistic effort to build the basis for a services market it would, however, be necessary to fund building a generic body of orderly data.[13]

At a glance – the order of funding:

Funding the development of climate services data infrastructure needs to balance generic and service-related tasks (building or maintaining the instrumentation and information infrastructure linked with communication and services infrastructures) as well as public and private interests (public money linked to private business, or public issues linked to private investments).

9) The order of data **provision**: via platforms, websites or via "fact sheets", is based on the dissemination of data as well as users' capability and capacity to work with the data; and it is clearly an interaction order:

a. **Data dissemination:** For this task, a multi-dimensional infrastructure is needed that comprises the information, communication, and service dimensions and merges them into a knowledge infrastructure.

I. **Practically**, dissemination works as this data curator describes: "*… we have various public interfaces to allow people to search and browse our catalogue. Then, depending on the licensing conditions, they may have to sign up for access. In some cases, data is public. They can then follow links from our catalogue through to web based download systems or more traditional FTP download systems. … lots of researchers also have login access to this platform which means that they can log in and run their own code on a big batch processing system right next to the data. So they basically log in to our computers and they manage their own workflows on our computers.*" (Int1-1;160:10-11) A related practical aspect is, however, that although there is competence enough around to help users to find their ways through the data, the service cannot go so far as to help them when they are not climate data experts themselves. Service here is expert-to-expert service.

II. **Communication experts:** "*We have now two experts in communication. We're working on developing very simple, entry level information, describing what we do on these fact sheets that*

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[13] "*I have grave doubts that without the right level of investment, in the right layer of the system, … So, we would always have little solutions to small parts of the problem without being able to manage the broader problem. So, what I would love to see is that the standards being built from the ground level up and then everything else benefitting from that. And I think most of the funding is coming in at the top level and at the user level and I think … it will never achieve what it hopes to achieve until we can address the foundations. So people will continue to create nice solutions that meet certain needs, but I think one of the really big requirements are the generic systems and work is still needed on that.*" (Int1-1; 160:42)

explain what is a climate prediction, why you could expect to predict the air quality in a city a few days ahead and things like this. So, very basic information, but, we are now moving a bit towards producing videos that could be used more as tutorials." (Int1-2; 162:10)

III. **Prototypes:** the goal is to document the whole process in which we go from the model outputs to something users can use; including e.g. enough entry level documentation that people connect with a click when they access the climate information, displaying uncertainties, quality control information. In fact, some organisations try to learn along with their users (Int1-2; 162:11).

IV. **Platform**: Sub-task 1 concludes that peak-portal may be reached. For instance, CEDA runs a big data processing platform called JASMIN, which currently holds about fifteen petabytes of high performance disk that is used by many communities but very significantly by the climate research community to carry out data analysis, inter-comparison, post-processing etc. (Int1-1; 160:10). This is the situation where improvement (with "users in mind") would deserve priority over setting up new portals.

V. **Knowledge hub plus data centre:** For instance, in Austria the CCCA provides regional scenarios and selected other kinds of data.[14] It has a typical broad task description, ranging from supporting and stimulating climate research in Austria to advising politics and society, including education, talent formation, and science transfer – everything needed for institutionalising climate knowledge.

b. **User space and tools:** Sub-tasks 2 above found that sites were not designed with users in mind. A huge barrier for users is whether or not they have the space to download the data needed and the tools to further operate the data. Then, it would be ideal "*having some consistent tool that you could use to talk to all of it*" (Int1-1; 160:37). Neither does it exist, nor do all the datasets support operating them with one tool only. Products from intermediaries for consultancies may include data and software (Int1-2; 162:9).

c. Intermediaries format data "***that's easiest for target users to understand***" (NASA, NOAA, and OSTP 2016, 28; bold text added here). Intermediaries help make sense of data and their role of seems absolutely crucial. Intermediaries should not only be considered as organisations, but also as organisational units or persons within climate data generating and handling organisations, tasked with facilitating communication with providers and users (communication infrastructure). Users, of course, are multiple and have diverse levels of knowledge, which is why intermediaries need to be highly flexible in adapting to diversity in users. In many organisations, there are people that could serve as intermediaries. However, funding is needed to create these positions or to give intermediaries the time to do their work.

  I. What these intermediaries can do also depends on the organisation they work at. KNMI, for instance, would not give advice on which scenario to use for policy making (this would be seen as impermissible setting of policy direction), but KNMI might help policy-actors achieve that decision themselves, by asking questions, giving examples, etc. (which would rather be considered as permissible policy support).

  II. One high-performance computing center (HPC), for instance, has a 'services group', "*trying to*

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[14] https://data.ccca.ac.at/, https://data.ccca.ac.at/dataset [31 May 2017]

engage with the outer world, … developing solutions for the private sector, and also engaging with the public sector, to provide them with tools to make decisions" (Int1-2; 162:2). This centre doesn't generate observational data itself, but develop models, run simulations, and disseminate the data publicly. The intermediary character becomes clear in the fact that the center doesn't perceive of it services as consultancy, but as bridging the gap between the global modellers and an operational context, for which consultancy companies wish to offer advice (Int 1-2; 162:12).

Key points – the order of data provision:

Data provision is as much a technical as a communicative task. Formats/genres of provision need to develop jointly with the relationship to users and their demands.

10) The order of **knowledge**: climate science, which is a highly specialised and sophisticated array of various disciplines, produces climate data, which is far beyond everyday users' capacity to process, presupposes a high level of data processing expertise; in addition, the background of users in different disciplines and professions together create a real threshold with regards to knowing how to use climate data:

   a. There are institutes that work in a more qualitative manner and might not have data processing experts that could handle or aggregate NetCDF/raster data; in this case the data processing would have to happen on the original provider side (Int3-0; 161:1) or through an intermediary dedicated to data curation. Other institutes employ specialists being able to answer special questions:

      I. **General knowledge demand meets general knowledge provision:** For example, one research institution mainly focusing at natural resources and life-sciences, investigating consumer behaviour in winter tourism, is interested in weather or climate data, but not at a detailed level, rather in aggregated data or ready-made analyses. In their work, they are exploring the question of what do tourists do when there is less snow. They are happy with all levels of climate data available at an affordable price, because they do not have very specific questions about the data (Int3-0; 161:2).

      II. **Specialised knowledge demand meets specific knowledge provision:** at the aforementioned HPC, they "*work in a tailored way. So, for instance, for the agriculture sector, we usually have to deal with slightly different data sources than for renewable energy. So, for renewable energy, what they are mainly interested in, is what will happen in the next few weeks, while for the food production sector, they are interested in either what will happen at the end of the crop season or what the climate evolution is going to be in the next thirty years. So, for instance, the wine sector is interested in changes in the climate in the next thirty years, because this is the time that it takes for a vine to grow and be productive, I'm talking kind of high quality wine, I'm not talking about wineries that are producing mass, large amounts of wine, wineries that are mainly working in the export sector. So, they are very interested in quality, and the quality is almost linearly independent on climate variables. So, we cannot use the same sort of climate simulations for the energy sector and for the agriculture sector. So, the data sources are different, the data segment is different, as well, the* *variables are different. So, for wind energy, it's obviously wind and temperature, for wine, it's temperature and precipitation, for wheat and maize, it's precipitation, radiation, wind and temperature. So, ... we have to work really on a tailored way addressing the specific problems that each sector is having, even the visualisation solutions that we develop are different with each one of those cases*" (Int 1-2; 162:13).

b. Exchanging and **working across aforementioned knowledge boundaries** on climate data has to deal with knowledge bound to practice – it is localised ("*around particular problems*" faced in a given context), embedded ("*in the technologies, methods, and rules of thumb*" used by practitioners in a given context), and invested ("*in methods, ways of doing things, and successes*" that show the value of the knowledge developed in a given context for specific people) (CNR-ISTI 2012, 62). Neither knowledge nor rules can easily be accessed, because it may partially be implicit, besides being diverse and specific. Knowledge boundaries need to be overcome and exchangeability needs to be achieved: (1) syntactic boundary (difference in syntax between languages used, including such for programming), (2) semantic boundary (information is differently interpreted in different contexts and communities of practice), (3) pragmatic boundary (the routines, policies, rules, problem perceptions and definitions, quality definitions, power relations within the community of practice) (CNR-ISTI 2012, 71-73).

c. **Boundary objects:** Sub-tasks 1 has established that climate services are characterised by fluid boundaries. Boundary objects are objects that can be shared across different disciplines, professions, practice communities, problem solving contexts. They can take the form of (1) repositories, (2) standardised forms and methods, (3) objects or models, and (4) (mental) maps of boundaries (Carlile 2002; Star and Griesemer 1989; Star 1989). They can overcome the aforementioned boundaries, when all involved sides are willing to converge their viewpoints and standards, share their knowledges and translate their languages. The fact sheets and tutorial videos the HPC uses would serve as boundary objects: "*very simple entry level information, describing what we do ... that explain what is a climate prediction, why you could expect to predict the air quality in a city a few days ahead and things like this. So, very basic information, but we are now moving a bit towards producing videos that could be more that could be used more as tutorials*" (Int 1-2; 162:10).

d. **Non-knowledge:** Occasionally, climate service providers, like all service providers, may learn to deal with the fact that (a) they do not really know what is at stake for a service user, and (b) that the issue of climate is only a (little) part of far more complex problems to be dealt with in a specific sector: "*a sector like renewable wind energy. ... One might think that wind is the thing, and that basically that's the main thing that matters. And when you start talking to them, of course, yeah, wind is important, and the production for the next day is important, but, it's not the only thing, actually. The integration into the network is very important. The definitive policy, that is applied in the different countries is important. How the market behaves is important. The wind is only a small piece of something that is very complex. … and the same thing happens in the Services Group here in the department […]. We are not trying to learn every single detail of the user decision process, but, where it gets very complicated is by the user not knowing everything about climate, and us not knowing everything about their business, identifying what is the common part of the whole problem, takes time.*" (Int 1-2; 162:15).

e. In brief, from both sides, providers and users, a high level of specialised knowledge is expected. It would be the task of **knowledge brokers and mediators** to facilitate communication across the boundaries of different organisations and practices. In fact, knowledge brokers also create a new body of knowledge, so called brokered knowledge.[15] This takes time to develop and the willingness to understand each other.

Key points – the order of knowledge:

Climate services data infrastructures work across boundaries of knowledge. They seek assistance by knowledge brokers and employ boundary objects. Different levels of knowledge need to be mastered, including uncertainties and non-knowledge.

11) The order of **marketisation**: consultancies charge users for services; most public organisations in climate data services offer their services for free. The following issues could so far be identified:

   a. **Willingness-to-pay:** Basic data providers and Intermediaries (user, who process data further in order to provide climate services) cannot offer certain services, because clients/users wouldn't pay the price. On the other hand, the provision of specific (qualities) services would require intermediaries to buy meteorological data where costs are prohibitive. Consequently, the spatial or temporal resolution can be compromised e.g., if data resolved on a daily basis are too expensive, then monthly data are used; the same goes for spatial data resolution (Int3-0; 161:4).

   b. **Costliness of higher resolution:** With regards to climate prognostics for tourism it would indeed be better to calculate on a daily basis, which would lead to a better correlation of quality of prognosis through higher resolution of climate data (although this is not necessarily the case for climate projections, as much as it is for historical climate records). For spatial climate prognostics, it is crucial whether data from a station that is further away is used because raster data for the focal area itself would be too costly; especially with regards to the characterisation of microclimates (Int3-0; 161:5).

   c. **Costliness of augmented data:** Data sources and data preparation for end users is a huge cost factor (Int3-0; 161:8). Projections relating to climate change, prognoses of climate actions are usually freely available, however, historical data and climate model data based on observational data (data from stations or raster data; used to calibrate models of demand, or climate sensitivity of tourism) can be costly (Int3-0).

   d. **Limits of free use:** Often data freely available for research is not free for commercial use (Int3-0; 161:8). So, from a business point of view, in-built restrictions in public data business models negatively affect marketability.

   e. The question of the **marketisation of services** most often derived from data gathered and processed through publically funded organisations has not yet been fully debated in the European context. Political as well as ethical considerations need to be addressed that consider issues such how the public providers of basic data and services could fairly participate in profits that for-profit organisations make.

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[15] *"Knowledge brokers are people or organizations that move knowledge around and create connections between researchers and their various audiences."* Meyer, M. (2010: 118).

f. The **marketisation of information about common goods** (natural resources, climate, weather, and related ones) follows a logic that doesn't always avoid a gap between the economically poor and rich, be it countries, organisations, or individuals, and those who cannot take part in a business model made for those able to pay. A political as well as ethical consideration could be whether climate services should be based on a for-profit or non-profit basis, and how.

g. **The democratic component** of climate services marketisation: Beyond government, there are numerous other organisations acting in the political sphere that could benefit from climate services, for example grassroots organisations, non-governmental organisations (NGOs), citizens acting in groups or alone. At the European Commission level, for instance, smaller NGOs and less organised citizens' interests often are supported with resources that allow them to keep on eye-level (in lobbying) with financially better equipped players; the same goes for legal aid schemes in judicial matters. As such, the climate services community should consider way to **sharing openly with citizens**, e.g. with vouchers or "pro-bono" services. In addition, consideration should be given to understanding to what extent climate services could contribute to, not only profit from, **open access** policies?

h. **Limitation of marketisation:** As for digital economies and infrastructure in general, there is a trend (in some areas, like in urban planning) "*towards emphasis on the role of government as enabler and facilitator of data-driven services*" (Barns et al. 2017, 21). For example, urban planners no longer seem to trust that market or technical mechanisms would themselves lead to smart and reliable infrastructure governance.

Key points – the order of marketisation:

Marketisation is more than just creating business models. It is an ongoing, coordinated negotiation of (divergent or shared) interest optimisation/maximisation and definition of a price. Interests may not always be economic, but political or ecological. For-profit services may in some cases only work as piggyback services with free offers.

12) The order of **usage**: Building a services market infrastructure cannot be reduced to efficiency and cost effectiveness, linear supply chain logics and processes of engineering and procurement. Rather, "*digital infrastructure requires understanding the relationships between the technological and social elements of such systems*" (Barns et al. 2017, 21).

One further issue that is not necessarily a barrier is the question of **climate services ethics**:

13) **Ethical frameworks** allow for the building and carrying out climate services. It can sensitise the climate services community regarding their responsibilities in gathering, processing, and interpreting climate information. It can also be a warrant against inadequate use, underutilization or even neglect of climate services that would otherwise have significant impacts on EU citizens' and societies well-being and wealth (EU-MACS 2016: 20). From a 'climate justice' point of view (c.f. Klein 2014; Martinez-Alier 2015; Shue 2014) as well as an 'ecosocial' standpoint (Cahill 2015; Fitzpatrick 2014), it is considered that there could be a human right to be protected against climate change-induced harm (Caney 2008), and it is asserted that this position can be best supported with combined utilitarian, prioritarian and

luck egalitarian considerations (Knight 2016).

a. A framework for climate services can be developed bottom-up by the climate services actors themselves (in existing collaborative organisations, such as WMO, who is actively pursuing this approach; c.f. Adams et al. 2015), and/or it can be implemented **top-down** by a government (nationally) or the European Commission (EU-wide). The advantage of the first approach is that climate services providers can define ethics, which take into account what they know about their businesses and clients, whereas the second approach would possibly guarantee a less actor-related, more universal view on climate services ethics. Perhaps both approaches will be started and merged at some point. What is important is that it is recommended for the market building the ethical approach would accept the users as core point of reference. This also means including them enough into the process of designing a climate services ethics.

b. The "Call for an Ethical Framework for Climate Services" paper (Adams et al. 2015):

    I. outlines a set of values (such as 'integrity', 'transparency', 'humility', 'collaboration'),

    II. on which a set of 10 "*principles of practice*" could be based,

    III. as well as four "*principles of product*".

    All these items, as they are coined, can contribute to quality control (e.g. "*communicate value judgments*", "*engage with their own community of practice*" and "*in co-exploration of knowledge*", "*provide metrics of their products*", "*mechanisms for monitoring and evaluation of procedures and products*", "*declare conflicts of interest*") and decency in interaction with other actors ("*communicate principles of practice*", "*understand climate as an additional stressor*", "*communicate appropriately*").

c. Further discussion could target issues, which are not explicitly mentioned in these ethical reflections:

    I. Would a **more explicit user orientation** ("customer first") help in giving the climate service community a better standing and a more balanced relationship to users, in brief: a more pervasive user orientation?

    II. The building of a European market for climate services will repeat both the internal relations and frictions of the economic area as well as those with the world market. Since climate change, as natural process, is a borderless phenomenon, would the climate services community be willing to **be inclusive** when it comes to the Global South, developing economies, (EU or other) national economies in crisis, etc.? Inclusiveness here means **aiding participation** (infrastructural, with service) and **sharing** of products that not all can afford.

d. **Procedural vs. principal responsibility**: A slightly different interpretation of taking on responsibility in climate services could be a governance approach that is less built on ethical principles, but more on procedure of coordination and collaboration, balancing of powers, interests and knowledge. In other areas of research and development, approaches of 'responsible innovation' have been coined, which could be translated into the climate services world. For instance, the so-called "Responsibility Navigator"[16] suggests a policy of supporting responsible behaviour that seeks to consider all voices concerned in the process. It is a multi-actor, multi-level, multi-

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[16] http://responsibility-navigator.eu/

perspective aid for all kinds of contexts, a meta-governance tool, to be appropriated wherever used, and thereby doing more justice to the specific context of use than approaches based on absolute principles or universal procedures.[17]

Not dissimilar to the aforementioned ethics framework paper, the "Responsibility Navigator" defines ten criteria that should help navigating towards enhancing responsibilities[18] They are, in brief, about the following:

i. **Ensuring quality of interaction**: 'inclusion', 'moderation' and 'deliberation',

ii. **Positioning and orchestration**: 'modularity and flexibility', 'subsidiarity' and 'adaptability',

iii. **Developing supportive environments**: 'capabilities', 'capacities', 'institutional entrepreneurship', and a 'culture of transparency, tolerance and rules of law'.

This approach allows for maximum responsiveness and actors' perspectives, and facilitate open debate, multi-faceted negotiation and mutual learning. Especially in a situation where climate services are still far from being an established community and market, such explorative governance would make much sense, also before setting fixed ethical principles.

Key points – the order of ethitisation:

In current climate services ethics discourse and policy, users are increasingly accepted as core point of reference.

Sub-task 3 Summary of Findings

Data is not just about data, but also practice, rules, organisation and politics, as well as knowledge regarding what the data says and what it does not say. It needs hardware and software, as much as humans and agencies that are needed to make sense of all the data gathered. Since the degree of data organisation in climate services and neighbouring areas are far from being fully established, an enormous effort is required before it is entirely fit for purpose by specific users. Data infrastructure and its governance is a complex, multi-level, multi-actor, and multi-perspective situation. As far as this can be organised through infrastructure, several particular layers will be **necessary to integrate the technological, personal, and social dimensions of usage**. Yet, it might be hard to develop a universal yet single solution covering all infrastructure dimensions that serves the user community effectively. Striving for this single solution may in fact lead to an overly complex structure making the interface at the end even less user-friendly.

We suggest a **nested set of infrastructure dimensions** (not layers in a hierarchical sense) could be an effective solution. Climate services needs infrastructure as the underlying foundation and framework for providing the services. But it is more than just a structure upon which services operate because infrastructure emerges in relation to organised practices. A realist view on climate services infrastructure sees it as "*something that emerges for people in practice, connected to activities and structures*" (Star and Ruhleder 1996, 112). Thus, it includes both the social and material, technical and business-related, scientific and

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[17] http://responsibility-navigator.eu/navigator/why-what-how/

[18] http://responsibility-navigator.eu/navigator/

governance dimensions on which climate services exist. Tasks like processing or visualising data may be linked to more than just one dimension, depending on whether the building of a meaningful corpus of data is the objective (information dimension) or rather the ex-change within the climate research and services community (communication); it may even address both.

Climate services infrastructure in this understanding is comprised of four dimensions (see Figure 11, p.50):

a) **Instrumentation Infrastructure:** this is what allows for the collection of all kinds of climate-related data; it includes (but isn't limited to) weather stations just as well as buildings, projects and partnerships, equipment such as computing facilities and satellites just as well as the practices and personnel, and the organisational set-up and institutional framework around these; e.g. national meteorological organisations are typically data-driven and providers of basic infrastructures (cf. Jakob 2015)

b) **Information Infrastructure:** information is the data plus meaning and organisation, which is all that is needed for qualifying data for climate-related and service-related use, the structure of storage as well as its preparation (curation) for dissemination; all kinds of data become climate data of various forms, gets linked with non-climate data, and is again based also on social practices, personnel, and the organisational set-up and institutional framework around these

c) **Communication Infrastructure:** the entire machinery of channels along which exchanges of climate-related ideas and information take place, which are not considered to be services - even before any service is given, the collectors and processors of data and information need to be in meaningful exchange about data and information (share all this or first of all exchange ideas about what could be worth further sharing or using for particular purposes; conventions and other shared rules of use are negotiated by communication); the fora, platforms, arenas where personnel work in and are interested in, relating to climate data and information; including the institutional and organisational structures as well as personnel needed for the service activities;

d) **Service Infrastructure:** all the channels and practices along which the actual provision of climate services takes place; including the users (clients, customers, business partners), as they bring their sets of ide-as about why and how they would use climate services (either in mere reaction which services are offered or in an attempt of co-production); including the institutional and organisational structures as well as personnel needed for the service activities. This infrastructure is the most complex dimension as it relies on and inter-sects with the other three dimensions fundamentally.

Essentially, all the dimensions interact like in a **matrix scheme**. Service relies on all other dimensions, while they exist and interact with or without the purpose of providing service to organisations outside the climate experts' own world.

Figure 11 depicts these four dimensions and provides concrete examples in each category. This figure indicates the interlinked nature of the infrastructure's components and their interactions. The Service Infrastructure, for example, relies on all other dimensions of the infrastructure, while the other infrastructure dimensions could also exist and interact without the purpose of providing service to organisations outside climate experts' own world.

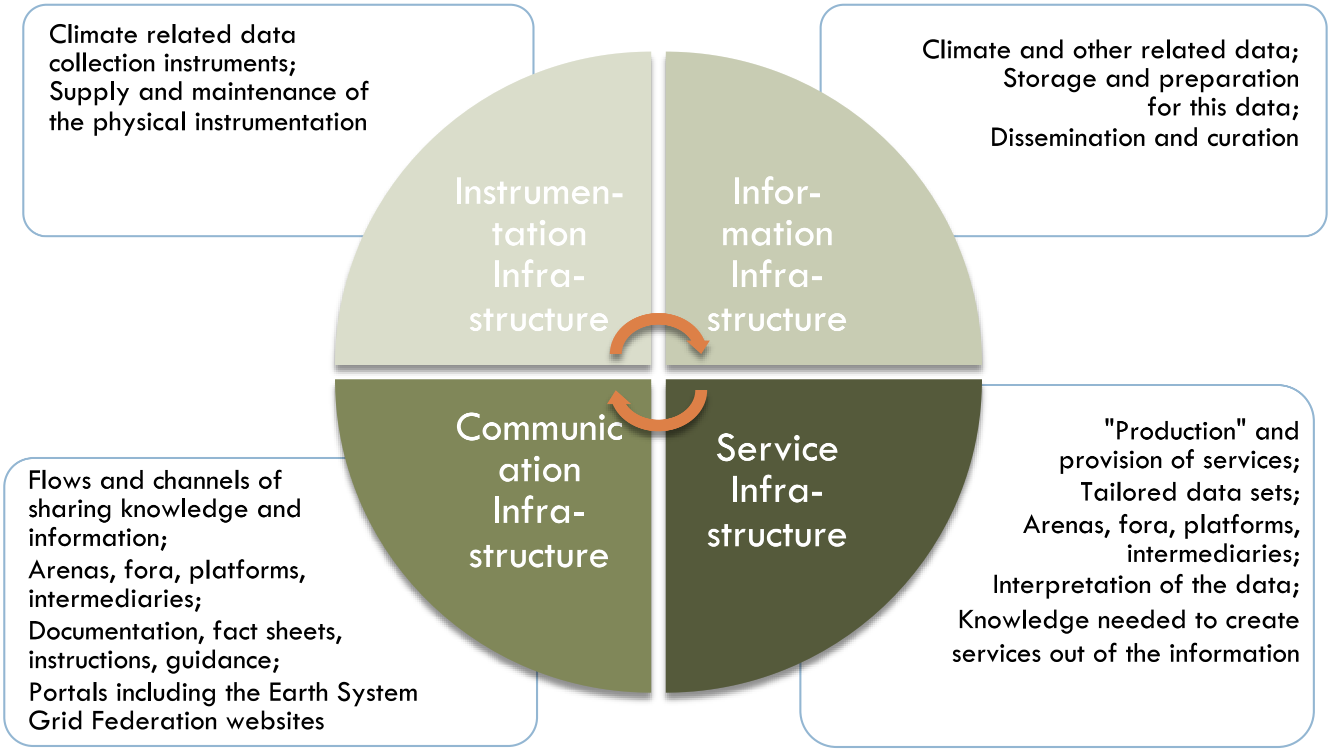

FIGURE 11: DIMENSIONS COMPRISING THE CLIMATE SERVICES DATA INFRASTRUCTURE

There are interesting **relationships between infrastructure components**, for example, between the Communication and Service components. The lines may be fuzzy between the two, with questions arising such as when 'Communication' does become 'Service'; or when is it mere data analysis, discussion of the technicalities of data ex-change among climate data experts; or what belongs to infrastructures enabling and enacting 'Communication' and 'Service'. The crucial difference between Communication and Service infrastructures is there is communication about data and standards etc. before there is service, and there is infrastructure needed to establish and "run" that communication. Service, in turn, might not always go so deep as to discuss the data technically or formally; what might mostly count for climate services users is the outcome. Market organisation aspects play a role both in the Communication infrastructure as well as in the Service infrastructure; think of, for instance, exclusivity rights on information or – in contrast – public monopolies for some segments of (the relaying of) weather and climate information.

Since these are dimensions, they are linked. So, when talking about data storage, it is necessary to think about **which dimensions are involved** in a given case, here for storage – not just information infrastructure, but also some communication infrastructure (otherwise it would be hard to find anything in there and to know where it comes from or what it is good for); also some service infrastructure, for experts say storage should be intelligent, or better: intelligible: allowing to find data according to profiles of service users' roles and demands.

Services, however, can also be provided **inside the community of climate experts**: when raw data provider in-teract with intermediaries, or when intermediaries among themselves dealing with various kinds of climate data that are not at every organisation' disposal or that not every organisation has the capacities for further processing. So, Service Infrastructure is both oriented toward “inside” community as well as “outside” customers.

In connection to this, but also in general: **Good data user governance** could become a great deal more reflexive, where this is not yet the case: “*The usefulness of existing tools and data should be evaluated not simply in terms of user feedback or feature requests; rather, it should also incorporate actual observations of users trying to use the data sets and tools*” (NASA, NOAA, and OSTP 2016, 32). First of all, there actually needs to be data user governance.

5. CONCLUSIONS

Our conclusions are phrased in hypotheses. They carry key ideas for better enabling climate services by overcoming major barriers.

Hypotheses

Hypothesis 1: A common data format and a common convention for data records and exchange will boost services and popularisation of climate data use (i.e. the importance of linking information and communication infrastructures with climate services infrastructures). Where harmonisation has not yet taken place, its implementation would reduce effort and costs for data management and curation; it would ease user integration technically and significantly, especially for expert users with distinct format preferences of their own.

Hypothesis 2: Role-specific finding aides, offered with real human interactive support, are crucial for successfully establishing and maintaining service relationships (i.e. the importance of linking information and communication infrastructures with climate services infrastructures). Benefit is created when an interface is designed with "search" or "finding" functions. As such, climate data portals and other digital interfaces should include finding and search functionalities, as well as aides (for pragmatic users) and tools (for the technical experts). Support and meta-support (support to help using the support) should go hand in hand with these functionalities.

Hypothesis 3: Climate services philosophies sometimes seem to pin all hopes on either a good portal or a good set of aides; the solution, however, seems to be more of a combination of both plus a good overview of available data sources, functional methods and active human (personal/personnel) engagement facilitating how users interact with both portals and aides (i.e. the importance of linking information and communication infrastructures with climate services infrastructures). Technology isn't the solution alone. Investment in human capabilities and capacities is as indispensable.

Hypothesis 4: The ultimate task of a good data infrastructure governance is to emancipate it (from technical-technocratic restrictions of specialists' mono-disciplinary 'boundary working') into a 'knowledge infrastructure' (Edwards 2010). In terms of an on-going, close to user multi-level, multi-actor, multi-perspective learning process – in brief, as 'convergence work' (Stegmaier 2009): a knowledge community must first emerge (a) in each service relationship and (b) perhaps across related service relationships to a higher aggregate level in the climate intelligence profession, where bridging gaps and working to converge standpoints is a key aim.

Hypothesis 5: Boundary objects can provide the chance to let disparate knowledges and interest, positions and conventions converge. There are numerous items that may enhance cooperation across the boundary of climate sciences into other domains, for example, fact sheets (rather not "guidelines", this could be a patronising way of dealing with the problem) and other aides, but also role models, vignettes of successful implementation of climate services in similar or typical cases, as well as singled-out problem issues a user has identified, which can be tackled from all sides involved and for which the value of climate services can be shown. For example, exemplary cases could be used (learning from past), or aspects of services that haven't worked well for the user at all as a curative exercise.

Hypothesis 6: It makes sense that free and open climate data is made accessible through a portal (e.g. Copernicus C3S) when flanked by support and tutorials that enhances inclusivity of a broader user

base. Portals can increase user experience if they are designed with the novice user in mind, rather than a climate data expert. This also includes making resources available to learn how to use the portal and the data. Creative, entrepreneurial types might be attracted by the increased usability and more accessible information and data. At the end of the day, freely available data becomes a problem, when it is not combined with appropriate levels of support. Novice users may better first be introduced with some (online) tutorial or course.

USING THIS REPORT IN THE CONTEXT OF EU-MACS

The hypotheses will be probed in stakeholder interactions and analyses throughout work packages 2-4.

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APPENDIX 1 – USABILITY SURVEY

QUESTIONS	SCORES				
Homepage	Strongly agree (5)	Agree (4)	Neutral (3)	Disagree (2)	Strongly disagree (1)
1. The website homepage is effective in directing and orienting users to the relevant information and tasks					
2. The homepage provides me with a clear understanding of the website's objective, including content and the features and functionality available					
Features and functionality					
3. Frequently-used tasks support user goals and are readily available and easily accessible from the homepage					
4. Users are adequately supported according to their level of expertise (e.g. short cuts for expert users, help and instructions for novice users).					
Navigation					
5. The navigational scheme (i.e. the menu or site map) is easy to find, intuitive and consistent					
6. The site or application structure is clear, easily understood and addresses common user goals					
Navigation					
7. A consistent and easy to find search function is available throughout the webpage					
8. Search results are relevant, comprehensive, precise and well displayed					
Data retrieval					
9. It was easy and efficient to locate climate data sets/information of relevance.					
10. The data registration process is expedient and straightforward					
11. I found useful and relevant guidance and tools on how to use these data (i.e. summaries, case studies, meta data, FAQ, best practices on how to use and interpret)					
12. There are features available to visualize the graph or map (hand tool, mapping tool, zoom in zoom out).					
13. Complex forms and processes to retrieve/obtain data and information are broken up into readily understood steps and sections					
14. Data files were available in conventional file formats (e.g X, Y and Z) (where applicable)					

15. Data files were easily downloadable/ exportable onto my machine (or usable in the cloud)					
16. Overall the process of obtaining data/information was not a cumbersome task.					
Performance and help					
17. Site performance and reliability doesn't inhibit the user experience (e.g. slow page downloads, long delays, broken links, bugs)					
18. Online help (including help feature, FAQ, contact us) is provided and is suitable for the user base					
SCORES		MAX. POSSIBLE SCORE			
General score (Qs 1-8 and 17,18)	0	50			
Data score (Qs 9 to 16)	0	40			
TOTAL SCORE	0	90			

Scoring scheme
- Very poor (less than 50 points). Users are likely to experience very significant difficulties using this site of system and might not be able to complete a significant number of important tasks
- Poor: (between 51 and 58) – users are likely to experience some difficulties using this system or system and might not be able to complete some important tasks
- Moderate (between 59 and 71) – users should be able to use this system and complete most important tasks, however the user experience could be significantly improved
- Good (between 72 and 88) – users should be able to use this site or system with relative ease and should be able to complete the vast majority of important tasks
- Excellent (more than 81) – the site of system provides an excellent user experience. Users should be able to complete all important tasks on the site or system