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Perspective

Developing climate information portals with users: Promises and pitfalls

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1. The emergence of climate services and associated climate data and information portals

The priority of climate change on political and research agendas fluctuates but got a recent boost after the 2015 UNFCCC Paris Agreement. The amount of climate data is surging (Overpeck et al., 2011) and so is the number of climate information portals.[1] Portal developers usually aim at serving "users" and therefore consult them. But how useful are the resulting portals really? And for whom? How effective was the involvement of users in developing the portal? This paper aims to provide some answers to these questions. To provide some historical perspective, let us go back to the 3rd World Climate Conference, organized by the World Meteorological Organization (WMO) in 2009, where it was decided to "establish a Global Framework for Climate Services ... to strengthen production, availability, delivery and application of science-based climate prediction and services" (WMO, 2009). This followed the introduction of the concept of climate services in the United States (NRC, 2001). In 2010, this GFCS subsequently developed a report "Climate Knowledge for Action: A Global Framework for Climate Services" as the basis for further work (GFCS, 2010) and in 2011 an Implementation Plan (GFCS, 2014). WMO defines climate services as "the provision of one or more climate products or advice in such a way as to assist decision-making by individuals or organizations" (Hewitt et al., 2012), also aiming to facilitate effective adaptation planning (WMO, 2016) In Europe, a system of climate services was proposed to be developed and implemented according to a Roadmap (EC, 2015). This Roadmap uses a more elaborate and arguably broader definition of climate services: "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)". In Europe, a climate services system, Climate Change Services for Copernicus (C3S) will be operated by ECMWF on behalf of the European Union with the aim "to support European adaptation and mitigation policies in a number of sectors".

The climate services discussion both globally and in Europe is emphasizing the usefulness of these services for a broad range of users, often emphasizing their relevance for decision making. Their development is very much framed from a climate data provider point of view and the proposed implementation appears very much centred around the development of digital data or information portals (Capela Lourenço et al., 2015). The development and maintenance of these generic tools require less resources compared to intensive, tailored face-to-face information brokering for multiple users and can reach an increasing number of institutions and individuals around the world who have access to digital information. Over the last decade, different public and private institutions, programmes and projects have developed information systems (portals, platforms) that provide access to an ever increasing amount and diversity of climate and climate impact data and sometimes tools to interpret and process these. In addition to portals that provide access to climate data, also portals are developed that more specifically aim at supporting adaptation to climate

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[1] In reports and papers about climate services both the term "portal" and "platform" are used. In this paper, we use "portal" mainly for digital information systems and interpret "platform" as an exchange forum that includes experts and users in addition to digital information. We recognize that the terms are often – sometimes confusingly – used interchangeably, in a few cases adding "web-based" or "digital" to the term "platform" to constrain the term to what we call "portal" in this paper.

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change (Street et al., 2015). Most of these systems try to take into account "user requirements" or "user needs". But to what extent are these systems actually providing the services that "users" need? And who are these users? And do they actually know what they want and how to use it? Users may have specific information needs that go unmet, or may not be aware of the existence of potentially useful information (McNie, 2007). Surprisingly, very little appears to have been done to systematically evaluate the extent to which climate portals really meet the needs of the targeted users, and how effective the engagement of users in the development of these systems has been. Usually no distinction in different types of users is made and "users" appear as one box in very complicated schemes of data sources and software tools. However, isn't the diversity of potential users at least as large as the diversity of climate services providers and products?

Box 1. The Climate Information Portal for Copernicus (CLIPC) project.

CLIPC (http://www.clipc.eu/) is a European research project that has developed a portal facilitating access to climate information of direct relevance to a wide variety of users, from scientists to policy makers and private sector decision makers. Information includes data from satellite and in-situ observations, climate models and re-analyses, transformed data products to enable assessments of climate change and impacts. Copernicus is the large European Programme for the establishment of a European capacity for Earth Observation. The Copernicus Climate Change Services (C3S) form the climate component of this programme. CLIPC is one of the so-called pre-operational components for these services, focusing on the development of a ''one-stop-shop'' with datasets which provide information on climate variability and change on decadal to centennial time scales from observed and projected climate change impacts in Europe.It also provides a toolbox to generate, combine, compare and rank climate change impact indicators. Expanding climate data volumes are supported with a distributed, scalable system, based on international standards. Metadata and guidance on the quality and limitations of data products and tools is provided. An on-going user consultation process feeds back into all the products developed within the project. Components of CLIPC are currently also considered to be integrated into the European information system on climate change adaptation Climate-ADAPT, managed by the European Environment Agency (http://climate-adapt.eea.europa.eu/). The CLIPC consortium brings together the key institutions in Europe developing and making available datasets from climate observations, modelling and climate change impact analysis.

A growing number of people with different objectives, backgrounds and skills require climate-related information that is useful for them to do their work, be it research, consultancy, policy development, or practice. The amount of available information about climate change, climate change impacts and solutions also continues to increase rapidly, for instance the global Coupled Model Intercomparison Project, Phase 6 (CMIP6) is expected to produce yet another flood of new climate projection data to be analysed, interpreted and used. More recently, projects like the Inter-Sectoral Impact Model Intercomparison Project (ISI-MIP) and the Agricultural Model Intercomparison and Improvement Project (AgMIP) add to the data flood in the area of climate impact analyses. A large number of climate change research projects have data or information portals as key deliverable. This led Barnard (2014) to diagnose a "Portal Proliferation Syndrome", with many users not knowing where to go and how to interpret the available data and information. Duplication and reinvention of wheels also leads to waste of resources. In one of the few systematic analyses of, in this case, climate knowledge brokerage platforms,[2] Hammill et al. (2013) suggest that the proliferation of these platforms demonstrates the potential information and communications technology-enabled knowledge brokering, that is to say to play the role of filter, interface and translator between knowledge producers and users. Yet, they observe that most platforms analysed continue to be mainly supply-driven and call for better knowing of the users and their demands. An important effort to improve the effectiveness of climate knowledge brokering is the establishment of the Climate Knowledge Brokers group, who released a guidance document describing the important role of brokers and how they should work (CKB, 2015). Many discussions about climate knowledge brokering and how to transform climate data into useful information guiding decision making seem to take place in a developing country context, due to the fact that in general the developing world is most vulnerable to climate hazards and climate services were set up and are promoted by multilateral organizations like WMO.

This perspectives paper intends to start a debate on the following question in a climate services context: what are success factors and pitfalls of developing a climate information portal for and with a broad range of users from different countries, with different demands, disciplinary backgrounds and skills? We address both the portal design itself and the process of engaging users in its development. We focus on the situation in Europe, building on experience in a number of European projects in support of the abovementioned C3S, in particular the CLIPC project (Climate Information Portal for Copernicus, see Box 1), a "pre-operational" research project for Copernicus in the light of experiences with similar projects (see Table 1).

2. How to assess the usefulness of climate portals and effectiveness user engagement

Neither the effectiveness of user engagement methods nor the actual usefulness of the resulting portals is systematically evaluated in most portal development projects, neither during nor after their implementation, or the evaluations are not reported in the literature. A few exceptions are noted here. An extensive review of national climate information portals discusses the content of 17 already existing scenario web-portals from 14 countries focusing on the limitations and possibilities in terms of visualization, dissemination, provision of data and target audience, but does not address the process of interacting with users (Sigel et al., 2016). Bulens et al. (2013) carried out an exploratory usability experiment in which three spatial discovery portals were assessed by five participants in order to identify the main obstacles in the user interface due to differences between supplier and user characteristics. They find that the structure of the discovery portals is determined by the way data experts like to work which is not necessarily the way users like to search answers to their questions. Houtkamp et al. (2016) report on a user requirements analysis for the AgMip project (a modelling comparison programme of impacts of climate change on agricultural systems), evaluating the effectiveness of the techniques and lessons learnt. They recommend a four-step user engagement process: stakeholder mapping and prioritisation; user identification; discussing and scoping the design situation; and persona- scenario construction (use cases with fictional characters

[2] Knowledge brokerage as intermediate between data suppliers and societal users refers to the translation of data into usable information. Hammill et al. (2013) use the term platform to describe digital portals, see footnote 1.

Table 1
Examples of climate information portals (source: Som de Cerff et al., 2015).

Characteristics/Portal Name	Website	Institution in charge	Scale	Main scope	Main identified audience
DRIAS	www.drias-climat.fr	Météo France	National	Downloadable data and exportable maps. Multi-model forecasts (CNRM, IPSL, EURO-CORDEX) under IPCC's SRES (CMIP3) and RCP (CMIP5) scenarios	French climate services providers
UKCP09 (UK Climate Projections)	ukclimateprojections.metoffice.gov.uk	Met Office	National	Climate projections for land and marine regions + observed (past) climate data for the UK. "The most comprehensive source of future climate information for the UK"	UK Climate-related activities
Climate Change Knowledge Portal	sdwebx.worldbank.org/climateportal	World Bank	Global	Generic climate indicators, impact-oriented indicators for Agriculture, water and natural hazards	Development practitioners & policy makers
Climate4impact (IS-ENES)	climate4impact.eu	ENES	Global	Downloadable data and exportable maps. Multi-model forecasts (CORDEX) and RCP (CMIP5) scenarios, SPECS. Downscaling, uncertainties. Part of CLIPC and Copernicus Climate Change Service (C3S)	Climate change impact modelers, impact and adaptation consultants and other experts using climate change data
Climate Explorer	climexp.knmi.nl/	KNMI	Global	Web application to analysis climate data statistically. Daily, monthly & seasonal data available. Station, gridded & climate indices. Time series and field calculations, downloadable data and maps	Wide range of users from climate scientists to policy makers, etc.
Climate.gov	www.climate.gov	NOAA (USA)	National + Global	Maps & data. Climate data + sectorial "actionable information": Agriculture & Fishery, Air quality, Civil Infrastructure, Coasts, Energy, Extreme events, Human Health, Insurance, Marine ecosystems, National Security, Tourism, Transportation, Water	Policy makers from all mentioned sectors (opposite)
Climate Adapt	climate-adapt.eea.europa.eu	EEA	Regional	Guidelines, maps, graphs, datasets (spatial time series, incl. projections), case studies, adaptation support tool + sectoral tools for Health	Adaptation policy makers and practitioners
GCM Data Portal	ccafs-climate.org	CIAT	Regional	Downscaled climate model data of various scenarios and RCPs	Wide range of users from climate scientists to policy makers, etc.
ECA & D	www.ecad.eu	KNMI	Regional	Observations: stations and gridded datasets. Climate Impact Indices, Indices of extremes. Downloadable data and exportable maps	Focuses on climate observations. Scientific and policy makers public

representative of typical user groups). In practice, these steps are not necessarily consecutive.

Taking into account the proliferation of (climate) information portals, it may be surprising that there is no agreed methodology to assess how effective these portals are or how effective user consultations are in their development. Often, only web statistics are collected and sometimes a user feedback button provided, but these do not provide a representative or systematic evaluation. A set of criteria often used for evaluating effectiveness of environmental assessments may be similarly relevant for evaluating portals: salience, credibility and legitimacy (Cash et al., 2002; also used by Houtkamp et al., 2016). We propose to use these criteria for the evaluation of the final product (the portal), again taking CLIPC as example. The effectiveness of the process of user interaction relates to the salience and legitimacy criteria. WMO (2014) distinguishes four criteria in the context of climate services for a user interface portal to provide "a structured means for users, climate researchers and climate service providers to interact at the global, regional, and national levels to ensure that the GFCS meets user needs for climate services": *feedback* (identifying the optimal methods for obtaining feedback from user communities); *dialogue* (building dialogue between climate service users and those responsible for the observation, research and information system pillars of the Framework); *outreach* (improving climate literacy in the user community, and literacy of the climate community in user needs); and *evaluation* (developing monitoring and evaluation measures for the Framework that are agreed between users and providers).

In the next sections we present the user engagement methods used in CLIPC, describe the results in terms of process and design, and highlight challenges identified. In the discussion section we assess the usefulness of CLIPC climate portal using the criteria salience, credibility and legitimacy as well the effectiveness of the user engagement on the basis of feedback, dialogue, outreach and evaluation. The conclusion chapter summarizes recommendations for developing climate information portals.

3. Methods for user engagement

For CLIPC to create a well-functioning, user-oriented portal for climate observations and projections data and an impact indicator toolbox, a detailed understanding of user requirements and regular feedback from users on prototypes of the portal were needed. A user engagement strategy was set up to (a) map experiences from other projects, (b) identify and prioritize user categories, (c) collect user requirements by questionnaire; (d) involve users panels in testing subsequent portal versions. Other climate information portal projects usually apply several of these steps as well, with some emphasis on (a) and (c). Fig. 1 summarizes the process of user engagement through the CLIPC project, which combines elements of user engagement methods from other projects.

3.1. Mapping experiences from other projects

Experiences with user consultation and engagement and users' data preferences developed in earlier and ongoing projects and initiatives were inventoried and analysed. The inventory of 66 projects, 11 of which were analysed in detail, suggests that accessibility of data and user relevance does not only require proper knowledge of potential user groups, their data and information requirements but also their preferences for ways to have data transformed (post-processed), communicated and disseminated. This demands regular interaction between the providers of the data and the users (e.g., Wirth et al., 2014; Hammill et al., 2013; Bessembinder et al., 2012; Swart and Avelar, 2011). However,

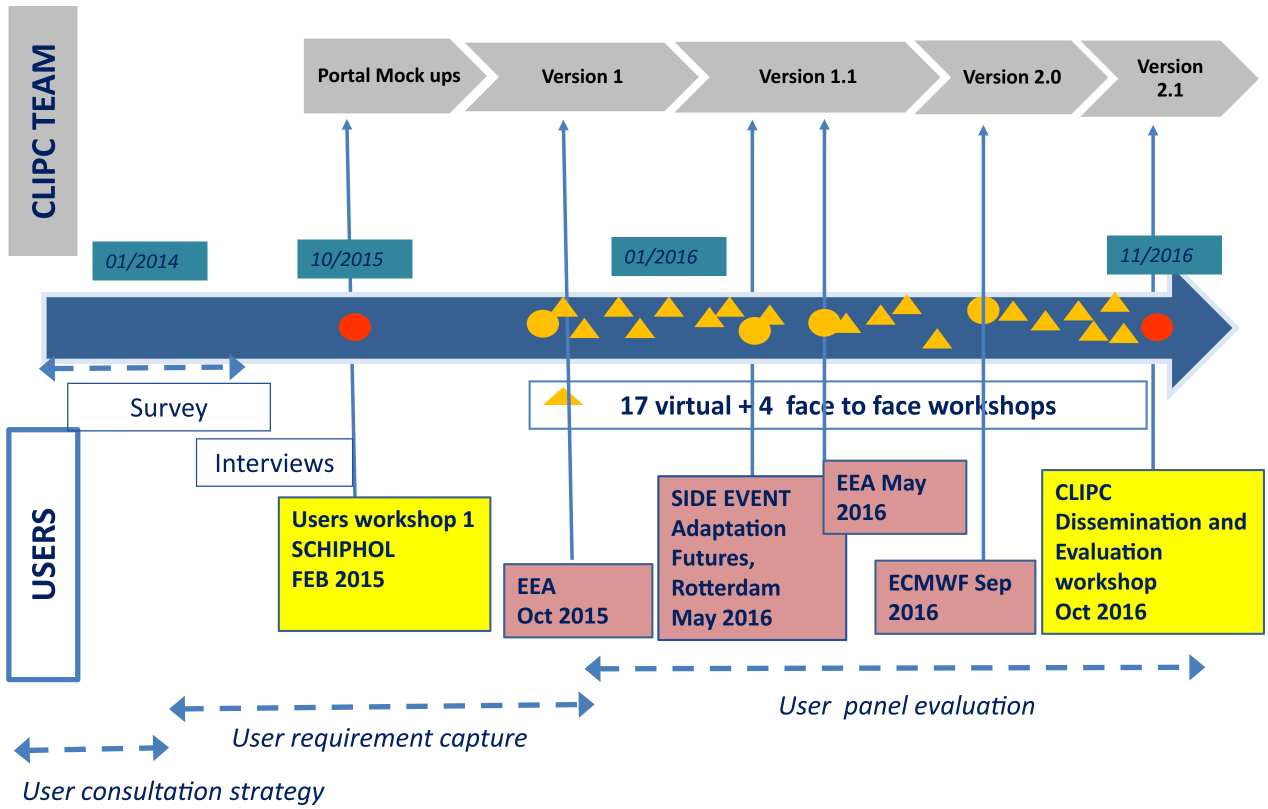

Fig. 1. Summary of user engagement process in CLIPC project.

experiences with user interactions in past and ongoing climate services projects show difficulties in effectively engaging users, in a sustained manner, in particular end users like policy makers and private sector decision makers (Groot et al., 2015), resulting in supply-oriented portals with limited relevance for the intended users (e.g., see Hammill et al., 2013). Experiences in other projects highlighted the need to devote sufficient resources for users' consultation, the difficulty to engage intended users in technical products like portals, and the need to engage users in a sustained manner.

3.2. Identify and prioritize user categories

Surprisingly, most climate services projects speak about the "users" and, while acknowledging that different users have different needs, do not distinguish between different user categories and climate services products or associated components. The above-mentioned GFCS and C3S programmes take a sectoral approach but do not distinguish between different types of users within a sector. Therefore in CLIPC an important step was to identify user categories, and consider to which extent these would require different types of information or different user interfaces and functionalities (e.g., for expert and non-expert users). A wide variety of potential users could be considered but for pragmatic reasons four categories were distinguished: climate scientists, climate impacts researchers, intermediate organizations (also called knowledge purveyors or boundary workers, such as consultants, environment agencies) and societal end-users (such as decision makers in government and industry). These users are not independent and some individuals may take on different roles in different contexts at different times or can work at different scales (Fig. 2).

In order to be effective, climate services should address the flow of information from the basic climate observations and projection data to impact and risk researchers, to knowledge purveyors and eventually to policy- or decision-makers. Feedback loops should in practice ensure that research and information supply is user-driven, but these loops are not always realised. Each category generally does not only seek information from the other categories (in Fig. 2 usually from right to left), but also within their own group. The implicit and complicating dimension in Fig. 2 is that generally the societal end-users work at smaller scales than the original global modelling sources of climate information. Research funders are interested in achieving societal benefits from their investment and tend to emphasise the societal end-users as beneficiaries of the research and climate services (e.g., EC, 2015). These societal end users may be defined as "people who are trying to address the impact of a changing climate". In practice, these actors usually lack time, skills or interest to directly use climate data or information portals and need intermediaries (knowledge brokers) as a link with the producers of climate and climate impact information. Therefore, CLIPC focused its user interaction efforts on the first three categories, although not excluding the fourth.

3.3. Surveying user requirements

The next key question is which kind of climate information potential users expect from climate service providers. For climate or climate impact information to be relevant for decision-making, they can be transformed, communicated and visualized via selected indicators. While neither the global nor the European plans for climate services exclude climate impact information, they do not yet focus very much on those either. CLIPC explicitly addressed climate impact indicators. To structure those, the project distinguished between the categories depicted in Fig. 3. "Tier 1" climate indicators are expressed in typical meteorological units, derived from observations, reanalysis or climate model experiments, like the Essential Climate Variables (ECVs), e.g., in terms of precipitation and temperature. They are generally characterized by the availability of large amounts of data with wide spatial and

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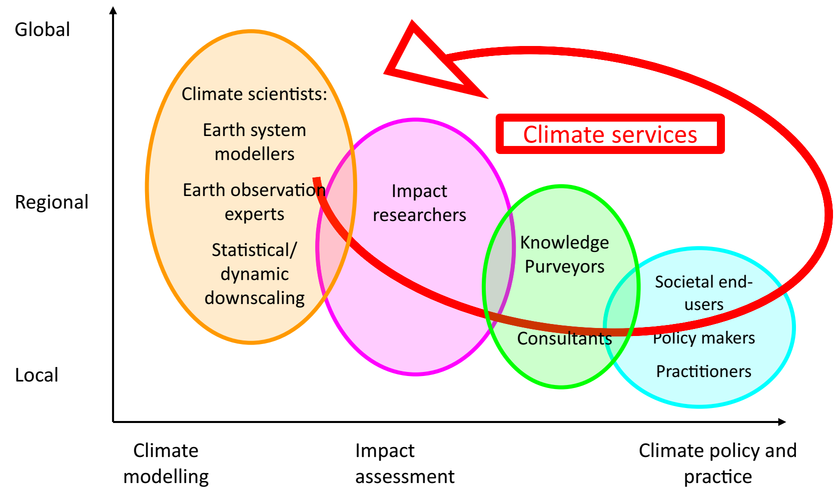

Fig. 2. Different interacting user categories in climate services.

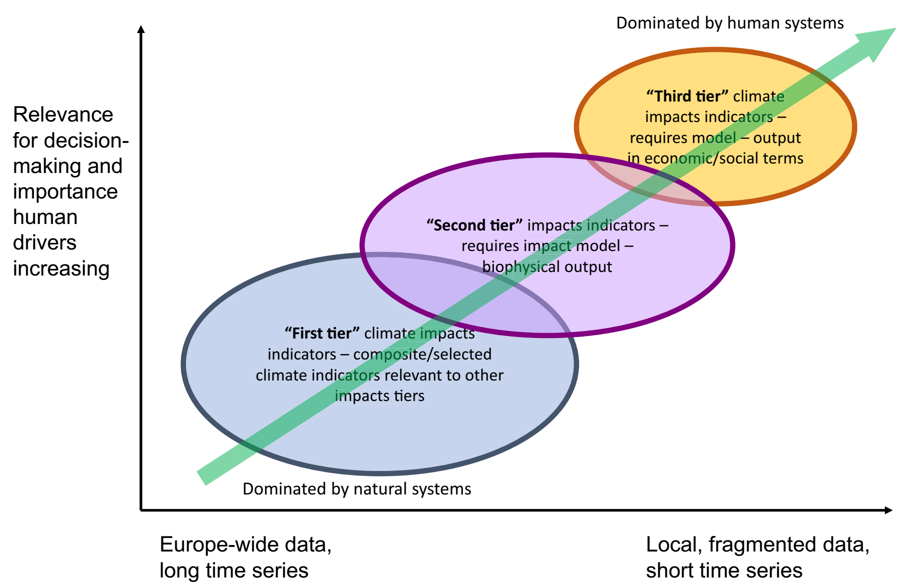

Fig. 3. Three tiers of climate and climate impacts indicators. Examples of "Third tier" indicators: flood damage cost estimates; loss of human lives, well-being; hydropower production changes; tourism comfort index; food trade losses; and biodiversity loss. Examples of "Second tier" indicators: Flood risks; Days with water temperature above threshold; Crop yield losses; Niches space for certain species; Plant/animal phenology; and Soil erosion by water. Examples of "First tier" indicators: Days with temperature above/below threshold; Length of growing season; Number of consecutive dry days; Snow cover; Mountain permafrost; and Sea level rise.

temporal coverage (long time series). With exceptions, they are generally less directly relevant for decision making. "Tier 2" indicators describe climate change impacts in biophysical terms, e.g., flood risk or crop yield loss. For projections, additional models (ecological, hydrological) are required. Availability of high quality climate impact data with large spatial coverage is lower, since most of these indicators are not routinely monitored and a system for coordination and harmonization of such indicators is much less well-organized than for climate data (Tier 1). Data often depend on projects which have a limited lifespan. "Tier 3" indicators are defined here as directly related to valued societal characteristics like human health and well-being or economic damage, e.g., the damages associated with flooding caused by intense precipitation. The relevance for policy makers can be considered very high, but data are even more scarce and fragmented than for the lower tiers. The magnitude of the ellipses in Fig. 3 reflects this. Boundaries between the tiers are not precise (hence the overlapping ellipses). For example the length of the growing season is determined by temperature (and may thus be considered as tier 1) but is defined differently for regions with different climates and ecosystems (and may thus be regarded by some as tier 2). With this approach, CLIPC moved already beyond many other climate services projects which are often limited to Tier 1. The European Roadmap even goes beyond this and suggests to include information on climate change response (adaptation and mitigation) in its Climate Services definition. The scope of "climate services" is clearly evolving, adding new actors to the climate services community, including knowledge purveyors (e.g., consultants, environment agencies) who play a crucial role in translating climate and climate impact information from the scientific-technical domain to the domain of policy and practice. The limited availability of information about socio-economic impacts of climate change (tier 3) may as yet constrain the relevance of climate services for many societal end users.

The results of the survey and qualitative interviews and observation of breakout sessions during the final CLIPC workshop, as well as experiences of the authors in a decade of working on projects related to climate services suggest that differences can be expected when mapping the four user categories and their

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interests in the type of information captured in the various tiers. Climate scientists would focus on tier 1 data, requiring a high level of detail and little post-processing functionalities (raw data). Climate impact researchers are expected to focus on both tier 1 and 2 data and appreciate access to post-processed data. Knowledge purveyors would be interested in all tiers, post-processed data and/or functionalities or tools to post-process data themselves. They would also need information about do's and don'ts in relation to selection and transformation of data. Societal end-users (decision-makers) would be interested in all three tiers but require to be presented with the information in a clear and concise fashion requiring little technical skills.

In CLIPC, based on these earlier experiences, an *on-line user survey* was designed and conducted to capture user requirements for climate and climate impacts data and information, meta data, uncertainty assessment and communication tools. The purpose of the online survey was twofold: 1) perform a quick scan of information requirements and 2) identify users' interest in participating in the development of the portal. Part of the questions addressed specifically the tier 1, 2 and 3 indicators. The 15-question survey was available online from summer to beginning of November 2014 and provided quantitative results (n = 90). The features and number of the population of potential users cannot be known in advance and thus the sample is not considered statistically representative of all potential users.

In addition to this survey, a series of *semi-structured, in-depth qualitative interviews* was conducted with a sample (n = 25) of users, so as to reach a more in-depth understanding of their requirements. The objectives of the qualitative interviews were to identify and understand:

- users' strategies for data consultation, including the purpose of data use, reuse and processing needs;
- perceived weaknesses and strengths of existing portals and other data sources in order to narrow the existing gaps which users consider to be important;
- the data needs (type of data, type of indicators, etc.) and to prioritize issues and indicators;
- users' perception of the added value of the project portal compared to already existing portals;
- users' preferences as to the ergonomics ((i.e., the ease and comfort when browsing)), functionality, and other features of the interface of the CLIPC portal, such as usage conditions.

The total amount of people that filled in the survey was 90 respondents, of which only 64 respondents filled in the whole survey. The majority of the respondents (35%) characterized themselves as intermediary/boundary organizations, followed by climate scientists (26%), impact researchers (23%), and societal end users (13%). The respondents came from 23 European countries which are well distributed across Europe, but with an emphasis on Western Europe. Most are associated with research organizations working on climate issues in combination with water management, agriculture or other environmental issues. More than two thirds of the respondents required access to climate data and climate impact indicators to give advice on climate data and climate impact indicators to others, often in combination with support to the development of adaptation strategies and plans, suggesting an applied research perspective. A very limited number of participants could be regarded as societal end users (decision makers), confirming the initial expectations.

Next, a *user requirement workshop* was organized in February 2015 focusing on the three user categories of the CLIPC portal which were considered to be the most important, namely climate scientists, impacts researchers and intermediary organizations, to maximize the relevance of the portal for users across Europe. The workshop included the testing and discussing of preliminary ideas, components and mock-ups; further specifying and prioritising requirements for a data portal and climate impact toolkit; managing expectations; and identifying needs and opportunities for further user consultation.

Finally, meetings organized by parallel projects in which project partners participated provided opportunities to identify users to be involved, to capture users' requirements and to organise test and advice on the CLIPC portal.

3.4. Engaging users panels in testing subsequent portal versions

Benefiting from the experience of projects like EUPORIAS, developing climate services for seasonal climate forecasts (www.euporias.eu), CLIPC engaged a group of interested users in subsequent consultations more thoroughly. These users had the project objectives in mind, and therefore could provide targeted expert judgment. To facilitate regular interactions, virtual workshops were held using teleconference facilities, allowing the project team to interact "graphically" with participants. A series of iterations was organized during the portal development phase, on technical components (e.g., feedback on mock-ups, on data retrieval procedures), concluded with a face-to-face demonstration event with selected users in Brussels in October 2016. Because of limitations of time, resources and skills, the CLIPC user consultation and engagement strategy focused on the quality and relevance of the CLIPC European portal in the English language and did not involve specific case studies or climate data tailoring activities which would require intensive interactions at a local level in local languages. This limitation is important especially for many non-scientific users.

4. Results in terms of portal design and user engagement

4.1. Portal design: survey and interviews

Users were asked to rank the main features of the portal according to their importance. Fig. 4 shows overall results in terms of perceived weaknesses and strengths of existing portals. Table 2 shows that different user groups have different opinions about weaknesses and strengths of existing portal (see Groot et al., 2013 for more details). Most respondents mentioned free open access and scientific correctness to be important. Climate scientists require availability and high quality of meta-data, whereas impact researchers highlight accessibility of data and information about uncertainty. Boundary workers attach specific importance to guidance to the selection and usage of climate data and climate impact indicators. Most respondents underlined the lack of guided search functionalities, the inability to combine and compare indicators, and the poor ability to visualize data as major weaknesses of existing sources of climate information.

The three main categories of users (climate scientists, impact researchers, boundary workers) were targeted for the semi-structured interviews. Interviewees distinguished 'user-friendly portals' from more 'technical' ones. They all emphasised the importance of clear and comprehensive metadata and confirmed that trust in portals depends on the scientific quality of the data, confirming the survey results in this respect. Other common issues raised during the users consultation on portal design included portal sustainability, reliability and adaptability; harmonization of data characteristics and tools across data sources, and user guidance for the portal. The sustainability of a portal relates to regular updates (with research findings and recent climate information) for a prolonged (or indefinite) time. Redundancy with others sources of climate information should be avoided. Participants, especially climate and impact scientists, highlighted the necessity of a high

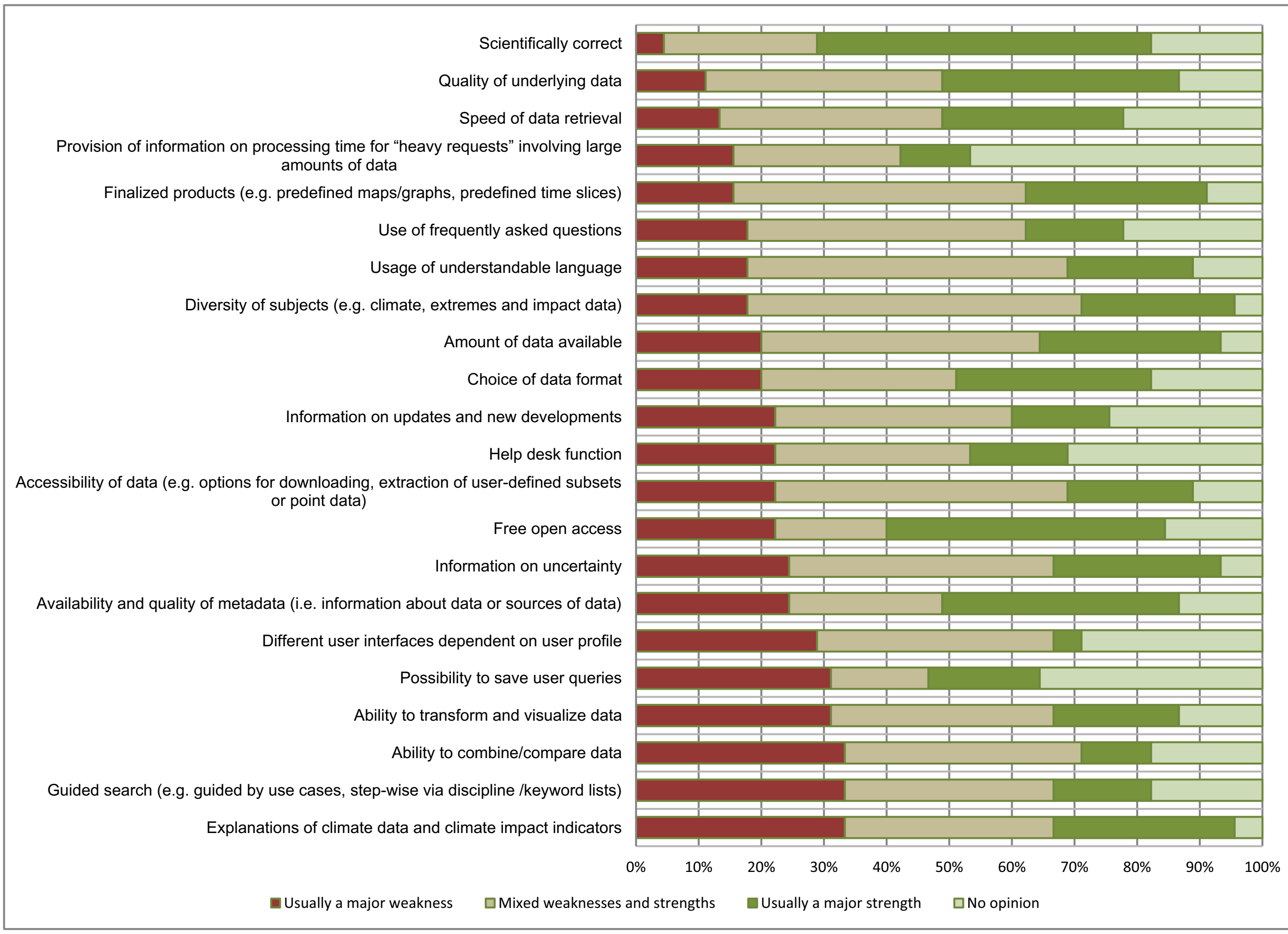

Fig. 4. Main overall strengths and weaknesses of existing climate information portals from CLIPC survey.

scientific data quality, with adequate metadata and data resolution as high as possible and meaningful. Beyond the harmonization of tools, there is also the need to harmonize grids, colours, formats and calendars. Users recommended that the portal design should take into account the diversity of users, their skills and demands, determining the diversity of products, data resolution, available datasets, and users layers. The possibility to save queries was also put forward as a way to adapt to the diversity of users. Finally, participants requested a guided search function, availability of use cases as examples, and a help desk.

4.2. User engagement: challenges encountered

The experience of the authors in various climate services projects mentioned above uncovers several difficulties to engage users effectively. Here we focus on the CLIPC project:

- *User fatigue.* Notwithstanding a very wide distribution of the survey, relatively few people take the time to participate, undoubtedly because many similar requests reach the target audience frequently, leading to user fatigue or just lack of time in times with heavy workloads. In the context of the major European research programmes, most climate-related projects include web-based information portals which are expected to be "co-created" with users.
- *Uncertainty about portal continuity.* One important consideration is that users question the continuity of project portals. For example, even if CLIPC is a so-called "pre-operational" portal in support of the development of the formal European C3S, a guarantee that it will be used in the context of the formal, operational phases of C3S cannot be given, because according to European competition rules the development of the operational system again has to be implemented through competitive bidding. This is a problem common to all portals which are developed in projects with a limited lifetime and no guaranteed long-term institutional embedding. This issue also relates to the credibility and legitimacy of a portal, which are considered to be larger when associated with some stable, recognized national or multilateral institution (e.g., UN, EU).
- *Incomplete state of portal development.* Many projects like CLIPC start, in the stage of proposal writing and first months of project implementation, with an inventory of what is known, in this case user requirements for climate information portals. For such projects, the first user consultations usually take place before the first portal version is available, not to have the developers pre-define the system and its interface. However, people often like to provide feedback on something that they can see rather than to provide answers to questions about what they actually want.
- *Poor regional representativeness.* Much like in other European climate services projects, the response and participation rate in surveys and user panels in CLIPC was much lower from countries in central, eastern and southern Europe, notwithstanding special efforts to engage people from those regions. One may expect that Europe-wide portals are more important for users in these regions than in Northern and Western European countries, where often users are well-connected to national sources, including climate experts and national portals. Interviews with

Table 2
Main strengths and weakness of climate information portals identified by different types of users (source: Groot et al., 2015).

User type	Portal strengths identified by users	Portal weaknesses identified by users
Climate scientist	Ability to combine/compare data Choice of data format Information on uncertainty	Scientifically correct Amount of data available Information on updates and new developments Free open access, Choice of data format
Impact researcher	Information on uncertainty Ability to combine/compare data Guided search	Scientifically correct Amount of data available Speed of data retrieval
Intermediary/boundary organisation	Explanations of climate data and climate impact indicators Help desk function Possibility to save user queries Guided search	Scientifically correct Quality of underlying data Amount of data available Free open access Availability and quality of metadata (i.e. information about data or sources of data)
Societal end user	Amount of data available Provision of information on processing time for "heavy requests" involving large amounts of data Different user interfaces dependent on user profile	Quality of underlying data Free open access Scientifically correct Usage of understandable language

people in these regions suggest however that lack of priority of climate change in policy and the related lack of time and resources in research is a key explanatory factor. The same misrepresentation of intended and potential users may apply to developing countries for global portals.

- *Possibly poor representativeness of user types.* There is uncertainty both at the side of the providers (who will be the eventual users of the system?) and the users (what can I expect from this information source?) that affects the representativeness of users involved. As the variety of data and information increases (e.g., from basic climate data to processed data to climate impacts and support for policy response), also the number and diversity of users increases. It is often unknown at the onset who the eventual users will be, which component of the system they are mostly interested in, and they may be different from the users who the developers had in mind originally. It remains unclear how representative users engaged in the process are for the range of potential and eventual users. Involving users with diverse skills and objectives in one session is unavoidable due to the real differences between users, and can reduce the effectiveness of the dialogue but also increase the mutual understanding of different needs and perspectives.
- *Unmet expectations.* User consultations lead to different types of feedback and suggested portal features, from "essential", to "important and feasible" and "nice to have but beyond the resources or scope of the project". It is important to prioritize portal features, manage expectations, and report on portal specific improvements responding to user feedback in each consecutive consultation session, but in situations of high time pressure and long "shopping lists" of requirements this is often not adequately done. Many users demand information or features that would help them with their specific, often local, work which would go beyond the scope of a digital portal and would require personal interactions or other types of tailored climate services.
- *User panel instability.* Participation of users in most information portal development processes is usually voluntary and not paid. This implies in practice that user panels involved in portal development is not stable: some participants will be able and interested to join different subsequent consultation sessions, following the development of beta-versions of the portal, others will drop out of the process or be involved at a later stage. This poses challenges for the developers, since different users may not only have similar or complementary but also conflicting desires.
- *Portal as important but insufficient element of a wider set of climate services products.* Many climate data and information projects have portals as their main outcome, with usually poor "helpdesk" possibility if any. At the same time, it is clear that portals cannot provide all information users seek. For specific purposes tailored information is required which often requires personal contact between users and experts knowledgeable about the content of the portal. As the market for climate services is growing, tailoring may mark the boundary between free and commercial services. "Guidance" was the most important demand from participants in the CLIPC consultation process.

5. Discussion: how useful are climate information portals and how effective the user engagement?

5.1. Credibility, saliency and legitimacy of climate information portals

Different users will weigh these criteria differently, for some salience and user-friendliness and for others legitimacy and credibility can be more important. In terms of *credibility*, users find it important that the data made accessible through the portal is credible – the portal should be at least as credible as other information sources, or more. As for all information portals providing access to data and information elsewhere, the eventual responsibility of data quality may lie with the original data sources, but in order for users to use the portal and reuse it, they have to judge the credibility, or reliability of the information provided positively. A climate information portal provides access to data sources that may differ in terms of credibility. This has to be taken into account in its design. In the CLIPC portal, one example is the difference between the climate data search and the impact indicator toolbox. The first provides access to established data sources, the latter is a novel development specifically developed for CLIPC allowing users to view, compare and combine climate impact indicators. Credibility also relates to a well-developed management and communication of uncertainties. In CLIPC, qualitative uncertainty (confidence) information will be provided for each indicator in the impact indicator toolbox based on expert judgement. In addition, attention is paid to a comprehensive and consistent treatment of metadata, a glossary, and other guidance material, including use cases (persona-scenario constructions). During the operational stage of a climate information portal, a systematic system of quality assurance and quality control (QA/QC) is required to consolidate the credibility of the system. Recognizing the importance of users confidence in data, as a first step in this direction CLIPC provided confidence fact sheets for all indicators. An expert-based confidence information system was included for climate impact indicators for which a quantitative analysis is not always possible.

Arguably a more challenging criterion is *saliency* or relevance, because of the unknown and dynamically changing diversity of users, and the equally large diversity of data products and portal components and services (like visualization, post-processing). One option would be to have different interfaces for different user categories with different interests and skills, but this adds clicks and thus makes the portal less user friendly. Users participating in the CLIPC testing were satisfied with the chosen design, but of course their representativeness remains uncertain. In particular, the very large amount of data sources and some features that are not available in other portals were appreciated. The latter includes the impact indicator toolbox and the MyCLIPC facility in which users can store the results of their queries and combine them with other data sources. A sustained dialogue, including training of providers and users and an effective user feedback mechanism, would ideally accompany the operational phase of a climate information portal. In order to remain salient, portals need to be flexible and co-evolve with the dynamic development of information supply and demands. Resources constraints challenge such sustained user interactions and flexible design, and often prevent multi-lingual portal versions, while those would potentially enlarge the user community and increase portal salience.

In terms of *legitimacy*, a key condition for engaging many users in CLIPC appeared to be the association with a formal European institution, e.g., the European Commission and its Copernicus programme. Also, association with global institutions such as WMO and its Global Framework for Climate Services or the IPCC Data Distribution Centre would be important in terms of legitimacy. In this context, the fact that CLIPC as a project may be intended to develop the "one-stop-shop" for climate information in Europe, but the use of the product cannot be guaranteed for the operational phase due to competition rules, was a major problem.

5.2. Evaluating the effectiveness of the user engagement process in developing information portals

As to the success of the user engagement and consultation process in climate services projects like CLIPC, the challenges encountered and discussed above imply that even if large efforts are made by portal development teams to adequately engage potential users, partly external contextual factors may limit the effectiveness of these efforts. In terms of the first WMO criterion for climate services user interactions, *feedback*, we think that there is not one optimal method for obtaining feedback from user communities, and a variety of approaches is needed to engage a sufficiently broad user group, e.g., using a combination of on-line survey, interviews, web-based testing and feedback, and user panels.

The second criterion, *dialogue*, is particularly tough to meet. Building and sustaining a dialogue between climate service users and those responsible for the developers of the information portal may be one of the most difficult criteria to meet for various practical reasons: the diversity of user categories, the lack of time of busy people c.q. mismatch of agendas, lack of financial or other incentives. In CLIPC, the success of building a sustained user community can be considered to be limited for these reasons: only a small number of users participated in more than one or two consultations. It can be imagined that for a better result more incentives are needed, such as a formal commitment by invited users or user institutions before or during the initial phase of portal development or financial compensation for the time spent.

The 3rd criterion, *outreach* by improving climate literacy in the user community, and literacy of the climate community in user needs, requires commensurate time and resources. In CLIPC, about 8% of the project budget was spent on user consultations, which may seem much, but means that more than 80% was spent on the technical tasks of building and filling the portal. The interest and expertise of people with the knowledge and technical skills to build an information portal can be limited regarding the understanding of diverse and changing user needs. Those skilled in dealing with a broad community of users are not necessarily well versed in judging the feasibility of particular technical portal functionalities. Effective interaction between portal developers, intermediaries and users requires a lot of time and good will which is often not available, with development and implementation of portals often being dominated by the tool builders.

Finally, WMO suggests *evaluation* as a criterion for developing useful user interactions for climate services, i.e. developing monitoring and evaluation measures to be agreed between users and providers. It seems that many, if not most projects, consider evaluation as something to be done after a project has been concluded, or at most mid-term for longer programmes. Often, because new projects ask for attention, evaluation of finished projects is neglected. Also CLIPC did not include a plan to evaluate the project, its products and the user interactions during the project itself.

6. Conclusions: how can the climate data flood be managed to address the needs of a wide diversity of users?

Regularly, new climate information portals are being added to the existing ones while a systematic evaluation of the usefulness of new and existing portals is generally lacking. The limited literature basis and authors experiences with a number of projects developing various kinds of climate information portals suggest that most of the developers of these portals have consulted users before and/or during the development process, but a systematic analysis of whom the future users are and how they should be engaged is either not done or reported. Often, even by formal international programmes like the global GFCS and the European C3S "users" are considered to be homogeneous and primarily policy- or decision makers. This is a very serious problem since arguably the diversity of users may be at least as large as the diversity of data sources and products and is changing fast. In particular, climate impacts researchers and intermediate knowledge purveyors (e.g., consultants or environmental agencies), are generally not distinguished as separate target groups, while they play an increasingly important role in providing climate information to societal end users who seldom use data portals themselves. Building on earlier recommendations (e.g., Swart and Avelar, 2011), we formulate our conclusions in the form of key recommendations for developing climate information portals for providing climate services:

1. *Take the wide diversity of users, their objectives, interests and skills into account when developing information portals.* In particular, recognize the important users "between" climate data providers and societal end-users, such as various types of impact researchers and, even more importantly, intermediate knowledge brokers. Different user groups in terms of sectoral interests and/or skills (e.g., non-specialist, specialist and niche user communities) may be best served by either different components of one portal or by different portals focusing on particular target groups. Involving sectoral or professional network organizations can facilitate identifying and engaging users (e.g., "sector champions" or hooking up to sectoral events, like in SECTEUR (Sector Engagement for C3S: Translating European User Requirements, https://climate.copernicus.eu/secteur). In addition to climate data, for impacts researchers, boundary workers and societal end users information about climate change impacts is important as well as socio-economic information to assess vulnerability and risk.

2. *Pay maximum attention to the continuity of information portals* to the extent allowed by national and international funding rules. Users invited to engage in co-developing information portals will recognize that project-based portals run the risk of not being sustained, seriously limiting their motivation and commitment. Seizing opportunities to further develop and link existing portals, rather than yet developing additional climate information portals, can prevent duplication and reinvention of wheels and make it easier to see the forest for the trees.
3. *Systematically assure and manage quality of data and information.* Users do not only require information relevant for their work, they also need to trust the data provided. In most cases, those maintaining and developing climate information portals are not the owners of the information – the responsibility for the quality of the data is with the original source. This means that the portal developers should communicate information about the quality of those sources. More questionable quality data may be made accessible, e.g. if they address key user questions, but in this case the quality of, or confidence in the data should be made clear to the user. While research projects do often not address this issue explicitly, it is of utmost importance for operational systems – the Copernicus Climate Change Service (C3S) therefore started to pay systematic attention to QA/QC in its "Evaluation and Quality Control" activities (https://climate.copernicus.eu/evaluation-and-quality-control-eqc).
4. *Recognize that information portals are a useful but often insufficient component of climate services*, to be complemented by additional services, such as tailoring of information products to local needs and local language services. CKB (2015) notes that users of climate knowledge require access to high quality information that is tailored to their specific circumstances, including a synthesis of relevant climate information, contextualised with an understanding of their sector and locality. The latter goes beyond what a digital platform can provide. Maintaining a help desk is a minimum requirement to allow researchers and intermediate knowledge brokers to provide adequate climate services using climate information portals.
5. *Assure that adequate attention is paid to well-developed guidance for selection, use and interpretation of data*, in particular for non-academic users. Such guidance may include use cases with persona-scenario constructions (fictitious users), a glossary, and information about confidence in data. Training courses or sessions can be organized to build capacity for particular user groups.
6. *Include functionalities to transform data.* Many users require transformed data rather than raw data, and often, dependent on their skills, want to implement this transformation themselves. This can include easy-to-use post-processing functionalities (statistics, downscaling), visualization, and a personalized environment (e.g., "MyCLIPC") to store and process information and combine it with personal, e.g. local data.
7. Ensure links and consistency between international and national sources of climate data and information.
8. In advanced countries with a well-developed system of national climate services, users will preferably acquire climate information through national contacts, suggesting that international portals should focus on countries with less well-developed climate services. Facilitating combination of data sources (e.g., regional sources with global information sources and, even more attractive, with local data) enhances the attractiveness of the portal.
9. *Plan for a sustained user interaction during and beyond the lifetime of portal development.* Effective interactions are needed between portal builders, users and often intermediaries. The different objectives, language, skills and expertise of these actors implies that adequate time and resources has to be spent on planning, implementing and evaluating the interactions that go well beyond what is customary in most projects. Developing software more "agile" from the start through collaboration between teams of users and developers with early delivery of a product followed by continuous improvement encourages rapid and flexible response to change, e.g., as done in SWICCA (Service for Water Indicators in Climate Change Adaptation, http://swicca.climate.copernicus.eu/). Also, adequate engagement of users or user institutions would be strengthened by formal commitment (e.g., as full project partners or via formal user committees) or financial compensation to be successful. This facilitates the support of the users' superiors for their participation during a project, and enhances the legitimacy of the product afterwards. Although through digital feedback arrangements like virtual consultations more users can be reached, complementary face-to-face sessions between users and portal developers can enhance mutual understanding.

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Appendix A. Supplementary data

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