USER ENGAGEMENT ACTIVITIES

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1. Introduction

In the last decades climate change has caused impacts on natural and human systems on all continents and across the oceans (IPCC, 2014). Socio-economic costs associated with climate change damage and need for adaptation are expected to escalate. Increased costs are not only related to increased frequency and severity but also to the timing uncertainty of the extreme events (van Alast, 2006; IPCC, 2014). Therefore, access to credible weather and climate information has the potential to improve human resilience to climate variability and change.

Within the context of energy industry, the variability of the weather and its behavior over time i.e. the climate, significantly influences both the supply and demand of electricity and poses the single biggest risk (known as climate risk) to the operation of the energy network. For example, in northern Europe, cold spells during winter months represent high-risk periods for the energy security of large areas (Ely et al. 2013) and in southern Europe, hot spells during summer months are the source of high risk to the energy network stability (Pardo et al., 2002). The highest priority for the energy network operators is to balance the energy demand with supply to avoid blackouts. Before the introduction of renewable energies, the demand was matched with electricity from generating plants, usually hydroelectric, nuclear and fossil fuels. This landscape has been changing rapidly with the integration of renewable energies into the energy mix (Spiecker and Weber, 2013). For instance, wind power provides the greatest share of renewable energy supply in Europe today (IPCC, 2011). Thus, this rapidly evolving energy system is also increasingly vulnerable to climate related risks due to its dependence on highly variable climate.

Advances in the science behind climate predictions are creating an unprecedented potential to provide climate forecasts over the coming months, seasons and decades (Doblas-Reyes et al., 2013; Goddard et al., 2010). Seasonal to decadal (S2D) climate predictions deal with forecasts for future times ranging between more than two weeks and slightly longer than one year (seasonal) up to 30 years (decadal) (Doblas-Reyes et al., 2013). S2D climate predictions allow energy sectors to adapt their short-to-medium term practices and plans to climate information, thus offering a unique opportunity to improve their resilience to climate extremes, climate variability and change. In Europe, Seasonal Climate Predictions (SCPs) have been evolving, although the skill of such predictions is low and differ significantly between areas (Brunet et al., 2010; Weisheimer and Palmer, 2014). Decadal predictions, on the other hand, are still an emergent area of research as a number of challenges remain regarding the development of the science behind it.

Climate services are climate information provided in a way that assists decision making by individuals and organizations to minimize climate risk. Such services require appropriate engagement along with an effective access mechanism and must respond to user needs. At the moment, the climate services domain is new and its application in the industry sector is still emerging. Consequently, a domain challenge is that many factors are unknown such as users, tasks and data. There is also low awareness among relevant businesses regarding climate information. Besides domain challenge, a major informational challenge is that the complex scientific data generated by these predictions is not readily interpretable and usable. Yet another challenge is to tailor the presentation of this complex information to the user’s requirement and skillset. Furthermore, evaluations of the climate service tools are often neglected and potential users are not always engaged in all stages of the development of climate service products. Thus, we are still on a learning curve in our understanding of how to tailor seasonal climate information to support decision-making in various sectors and ultimately facilitate its uptake.

The challenges associated with the use of climate service information require numerous interdisciplinary efforts. First, in order to identify and characterize the domain and the problem, wide-ranging engagement between scientists and industry stakeholders is required to fully understand users and their needs. Secondly, there is still not enough empirical evidence to confirm how people interpret complex scientific data (Spiegelhalter et al., 2011, Taylor et al., 2015). This complexity demands knowledge from different disciplines to be joined together to communicate climate prediction data so as to avoid misinterpretation while translating domain knowledge to business needs (McInerny et al., 2014). Finally, well thought-out, human-centered design and visualization can enhance legibility and cognition of climate information and thus, greatly contribute to the development and communication of climate services (Moere and Purchase, 2011; Quinan and Meyer, 2016). Overall, fostering interdisciplinary teams of climate scientists, communication specialists and design researchers brings varied expertise and competences in all stages of climate service development. Such collaborations improve the usability of climate predictions, tailor climate information to answer actual needs of users and better communicate uncertainty. Essentially, it bridges the gap between the state-of-the-art climate predictions and the readiness of stakeholders to use this novel information.

To this end, BSC climate services group participated in the RESILIENCE project to initiate a co-production process of an end-to-end climate services product that provides a comprehensive assessment, description and dissemination of probabilistic climate forecasts tailored to the European renewable energy sector. The project brings together two important, cross-disciplinary research groups on climate and energy. Two main objectives of RESILIENCE are to collect and assess the most comprehensive set of wind speed and temperature predictions over Europe on sub-seasonal to seasonal time scale and to produce tailored climate services for end users of the energy sector using these climate predictions. RESILIENCE also draws key lessons from other similar climate service-related European projects such as Climate Local Information in the Mediterranean Region Responding to user Needs (CLIM-RUN; 2011-2014), European Provision Of Regional Impacts Assessments on Seasonal and Decadal Timescales (EUPORIAS; 2012-2017) and Seasonal-to-decadal climate Prediction for the Improvement of European Climate Services (SPECS; 2012-2017). However, the RESILIENCE project covers additional aspects not covered by these European projects. These aspects are:

a. focus on shorter climate time scales, which range between two weeks and several months into the future, because they are the most relevant for energy operations,
b. focus on climate variability and prediction over Europe and more specifically, over the Iberian Peninsula
c. development of a climate service that is specific to network operations and the balance between supply and demand
d. communication of the climate service for energy via a User interface Platform (UIP) that will facilitate the co-production and stimulate a bottom-up interaction with users
e. development of targeted communication material of climate predictions for the energy sector and
f. development of an illustrative regular newsletter for Subseasonal-to-Seasonal (S2S) predictions, to engage with users.

The main objective of this report is to summarize the many user engagement activities that were carried out under the RESILIENCE project among various industry stakeholders from the energy sector by the BSC climate services group. Section 2 summarises these user-engagement activities in detail, particularly focussing on identifying climate service users and their specific needs (section 2.1), developing tailored climate service products to meet those needs (Section 2.2) and communicating complex scientific information through effective techniques (Section 2.3). Section 3 draws upon the lessons learnt from these specific user engagement activities with a final conclusion in Section 4.

2. User Engagement Activities

2.1. Identifying Users and their Specific Needs

Building a good climate service product requires improved understanding of users, their needs and how and when various types of climate information can be incorporated into the decision making processes. To improve this understanding, the RESILIENCE project pursued a range of tasks such as conduct in-depth interviews with stakeholders and other users of energy network operations and collaborates in various workshops with other similar climate service project-groups while focusing on the European renewable energy sector.

A user engagement workshop was carried out by the BSC climate services group in collaboration with EUPORIAS, another European project that aims to increase the resilience of the European society to future climate variability through the use of climate information in decision making across different sectors. While the workshop covered cross-sectoral climate services, RESILIENCE focused solely on the European renewable energy sector. The workshop mainly aimed to understand who the users of climate services are and their needs and expectations on climate information. The workshop began with presentations from 3 existing European climate service projects—Joint Programming Initiative "Connecting Climate Knowledge for Europe" (JPI Climate) , the Enabling CLimate Information Services for Europe (ECLISE) and the CLIM-RUN project. The participants interacted with each other and brainstormed to share their knowledge, expertise and concerns. They were divided into groups and asked to identify (potential) users of climate services within the energy sector of Europe. They were also asked to explain why and how these users were using climate information and to sort these users based on the timescale of the climate predictions they required. Work sessions were also dedicated to understand the barriers and limitations of the use of climate services with the aim to explore potential solutions. Existing climate service providers also shared their experiences with users and the issues they faced.

A session was also dedicated to depict the interactions and relationships that exist between users and producers of climate services. The “Conseil Supérieur de la Météorologie” (CSM), which is a national level users’ consultation body, gave a presentation in this session. Its mission is to evaluate services provided by Météo-France (MF) to its users as well as to formulate recommendations on behalf of different users from public and private sectors. CSM is an interesting example for a sustainable interaction and dialogue between users and producers. It facilitates a customer focus at the national level and provides a global view of needs, demands and possible co-ordination of various demands. Another session aimed for an in-depth exploration of the climate service provision chain—from creating supply to meeting demand. How does the climate information travel from the providers to the end-users was the main question that was addressed. Various parts of the climate service provision chain were explored including their inter-relationships.

The wrap-up session of the workshop included presentation of initial findings of the survey developed for the SPECS project. SPECS undertakes research and dissemination activities to deliver European climate forecast systems with improved forecast quality and efficient regionalisation tools that produce reliable local climate information at S2D scales. The goal of SPECS survey was to assess which recently occurred climate events were considered most interesting by the stakeholders. Based on the responses, it was evident that most of the users were interested in seasonal events related to temperature (including extremes). Lessons were also drawn from other case studies of climate information usage from the USA and South America.

The partnership with SPECS also involved identifying multiple user profiles by understanding both pre-construction and post-construction phases of wind condition analyses. The objective during the pre-construction is to ensure that the site characteristic secures wind-farm projects and that of the post-construction is to optimise the operation of wind-farm and energy trading. The pre-construction phase can potentially benefit from near-term forecasts and even multi-annual or decadal forecasts as part of the project uncertainty. For post-construction, users are more concerned about having advanced information on the wind conditions of the next season. Discussion sessions and meetings were carried out among interested potential candidates such as Meteologica, AWS Truewind or Vortex. The main aims of these activities were to (a) provide visibility to the climate service projects and its by-products among the wind industry (b) familiarize non-climate specialist users from the wind industry with S2D functionalities, information and products, (c) discuss various user needs and identify opportunities for customized solutions based on new generations of S2D forecasts and (d) to analyse and discuss potential joint-actions to allow dissemination of S2D products among the wind industry stakeholders. The identified stakeholders were manufacturers of wind energy, project developers, project owners/investors, consultants, construction engineering companies, wind power research organizations and public organizations interested in promoting, regulating and policy making within the wind energy sector.

2.2. Evaluating Usability of Climate Service Products

Evaluating usability of climate service products requires evaluation of how users are interpreting the provided climate information because it impacts the way they make use of this information in decision-making. First, the users must be made aware of the potential of climate services in building an energy network that is resilient to climate variability and change. Then, effort must also be put into effective communication of climate information in order to avoid misinterpretations. For example, while Global Producing Centres (GPCs) show their own probabilistic forecasts, there is limited consistency in the communication of these forecasts between the centres. This makes it difficult for users to understand and interpret the products or make best use of them. Therefore, a communication protocol that encompasses both the effective dissemination of climate information for user awareness and the evaluation of the tool used for communication helps introduce a standard format and message to the users.

2.2.1. Effective Dissemination of the Potential of Climate Information

First, to ensure that users are aware of the usability of climate information, the RESILIENCE project produced and disseminated different fact-sheets (www.bsc.es/ESS/arecs). Some of these fact-sheets summarized the risks created by the changing availability of the wind resource over S2S time scales and its impact on the balance between energy demand and supply. Other fact-sheets focused on describing the S2S climate information, the meaning of probabilistic predictions as well as their application to users' decision-making in the energy sector. Others addressed issues such as forecast quality assessment or added value of climate predictions for energy network management. Fact-sheets were made available via the RESILIENCE User Interface Platform (UIP), called Advancing Renewable Energy with Climate Services (ARECS). Other resources were also made available in ARECS in the form of newsletters and wind bulletins where forecasts were compared to observations to show how climate predictions issued in an operational context can guide decision-making. In addition, a case study section where users can have a look at key events from the past relevant for particular industrial partners was implemented. Other documents such as technical notes, publications and other resources (videos, apps, etc.) can also be found in this section. An image catalogue was also included, consisting of a repository of images obtained as a result of using the best information from S2S climate predictions. Finally, a feedback form was included in ARECS in order to facilitate feedback between users and providers of the climate service.

During EWEA Annual Event 2015, a workshop "Working Group on Seasonal Predictions for Wind (SP4Wind)" was organized, which involved a range of companies and organizations in the Spanish and European energy network operations (EDPR, EDF, Alstom, Iberdrola, EnBW, MeteoLogica, AWS Truewind or Vortex among others). The aim of the workshop was to build a collaborative forum to support the dissemination of seasonal prediction information for the wind industry and to facilitate the exchange between experts and stakeholders. It gathered 11 attendees from: General Electric Spain, EDF R&D, AWS Truepower, ZSW, WeatherTech, SIEMENS, ENECO, Iberdrola Renovables, Casa dos Ventos and Meteo-France. During the workshop, an open discussion was organized on various topics related to the integration of climate predictions in the wind industry workflows, such as: reliability of predictions, added value compared to climatology, integration with El Niño and NAO information and potential improvement in the analysis of anomalies and extreme events. Among the participants in the exhibition other users that showed interest were intermediary companies that already provided weather and short term weather predictions for wind resource assessments.

In the context of the RESILIENCE project, we also conducted Europe-centered case studies to demonstrate the effectiveness of climate predictions in mitigating climate risk. For example, we analyzed the wind speed and temperature predictions for winter 2012 to assess if its usage could have minimized the risk of unexpected energy network imbalance. In 2012, the above-average wind output and low demand due to higher than average temperatures during the winter season created considerable disruption to the German energy network (Morison and Mengewein, 2013). This climate anomaly impacted the day-ahead prices, turning negative for the first time and disrupting the stability of the grid system. Other case studies, like the wind resource over the North Sea or the impact on the demand of the 2003 and 2006 extreme summer temperature (Rebetez et al., 2009; Weisheimer et al., 2011) were also chosen for consultation with the RESILIENCE industrial partners. It was evident that most of the positive case studies in the literature occurred when there were strong interactions between users and producers. This reiterated the need for wide-ranging user engagement in all stages of climate service development.

The final outcome of the RESILIENCE project is an online interface built to serve the objective of developing a user-friendly interface to communicate the results obtained. Given the specific focus on developing a climate service for energy network management based on the priority of securing the energy network, RESILIENCE project aimed to greatly advance and improve the initial concept of ARECS. ARECS stands for Advancing Renewable Energy with Climate Services (www.arecs.org) and is the seed of the UIP to be developed as part of the RESILIENCE project. The ARECS initiative helps the energy sector manage the risks and exploit the opportunities of future variability in wind and temperature resources over monthly to decadal timescales. Basic assessments of seasonal forecast are performed for wind and solar resources, alongside a simple communication for small range of end users in the energy sector. During the design stage of this platform, particular attention was placed to the different sections of the climate services, including their structure and layouts as well as its compatibility with activities from international initiatives (IRENA Global Atlas, Climate Services Partnership-CSP, etc). The RESILIENCE climate service for energy has been represented at many international events to collaborate in the co-designing of the communication material and the tools.

2.2.2. Evaluate Effectiveness of Communication of Climate Information

A workshop “Building two-way communication: A week of Climate Services” was organized in collaboration with CLIM-RUN project to evaluate the end-user perception regarding the communication of the seasonal climate forecast information. Participants were brought together to assess the gap between the scientific data available and the information needed by decision-makers. Participants were divided into groups and each group was assigned a Forecast Centre (FC) website for evaluation. They were introduced to the FC's online homepage to access the probabilistic forecasts and verification information. Participants had to find the seasonal precipitation forecast corresponding to the DJF 2009/10 time period. They were then asked key questions to evaluate their ability to understand and interpret the forecast, its corresponding verification and their visualisation preferences. Feedback was also sought on the users’ perception of the main problems regarding communication of forecast information, barriers to the wide-range dissemination of actionable climate information and possible improvements that could be made. An open discussion among the attendees was organized at the end and a proposal was made to initiate a seasonal wind outlook forum that could run in parallel with the TP Wind bi-annual meetings held in Brussels.

Direct interactions with the users are necessary to evaluate climate service tools and get their feedbacks to improve future versions as well as to provide an indication of the success of the tool in its current form. ARECS provides a platform for science and industry to discuss and provide such feedbacks on climate risk management and to optimise the planning and operational strategies for balancing renewable power supply and energy demand. It is disseminated to and interactive with all the actors in energy and climate for both research and industry.

RESILIENCE also conducted interviews that were designed and tested to favour the co-production and to evaluate the efficiency of the communication of the climate predictions. Interviewees were network operator decision makers and providers such as EDF, Vortex, Red Electrica Espanola, the National Grid UK, and E.ON. The interview covered key "modes" through which the usefulness and usability of forecast information was determined. For example, communication modes included forecast assessment, decide the best tools to make an evaluation of the prediction value, and forecast interpretation and detect additional information needed to facilitate the usability of climate predictions (Pidgeon and Fischhoff, 2011). A range of examples of assessments, evaluations and descriptions were used and the best option was identified including analysis of its possible improvements to refine the communication of the climate prediction to fit the needs of end users. These feedbacks on the different approaches of using climate predictions to guide decision making related to the forecast communication was taken into account while designing ARECS. It included using best options suggested by the end users regarding colour range, design, the most effective way to show skill and reliability and interpretation.

2.3. Use of Visualization Techniques to Communicate Climate Information

Improved communication is fundamental to encourage the use of climate products by end-users. While developers strive to make climate information tools 'intuitive' and 'easy to use,' achieving this in practice is often not easy. Potential users, although usually domain experts, may not always understand all aspects of a complex information and in particular, the nuances of the way data is presented. A lack of understanding of what the interface is showing and how to interact with it does not signify ignorance on the part of the users. Rather it highlights that the aspects of the interface are confusing or difficult to interpret. Then, a challenge for developers of complex tools is to make them as easy to interpret as possible.

The_current approach to visualizing probabilistic forecasts is to present them in categories e.g. terciles or quintiles. In some cases, the probability of the most likely category is provided, where the categories are formulated with respect to a climatological reference. Probabilistic forecasts are accompanied by forecast verification, which addresses the accuracy (how close the forecast probabilities are to the observed frequencies), the skill (how the probabilistic forecasts compare with some reference system) and the utility (the economic or other advantages of the probabilistic forecasts) (Jolliffe & Stephenson, 2012) aspects.

Global Framework for Climate Services (GFCS) initiative along with SPECS, EUPORIAS and RESILIENCE projects conducted a study to establish a visual communication protocol for probabilistic forecasts for the first time. The study investigated challenges associated with climate information visualisation and communication while also identifying ways to improve this for probabilistic seasonal climate forecasts. In the study, examples of probabilistic forecasts for precipitation for December-to-February (DJF) season of the year 2009/10 were analysed. The time period was selected because an El Niño was underway, when climate forecasts are shown to be more accurate (Goddard & Dilley, 2005). When these events occur, there is a clear opportunity to incorporate climate information into decision making processes for climate-sensitive sectors. Forecasts from 13 Forecast Centers (FCs) were compared.

General aspects of the websites were analysed. For example, if a login is required, number of clicks from the FC's homepage to the required information, availability of website in English. The second aspect focused on the forecast products available and their types, time periods available and how far in advance the information is issued (i.e. lead-time). The corresponding forecast verification products and type were also assessed in a similar way to the forecasts. Finally, forecast visualization techniques were assessed. The appearance of a legend, indication of units, type of labels and the colours used in the legend were examined. Descriptive information, such as the forecast product, verification type, the probability of categories, the region, the variable and the time period were also evaluated.

3. Results

3.1. Identifying Users and their Needs

Climate services were mainly used to improve management of organizational activities, products and outputs to increase efficiency and also to increase profitability, for those in the private sectors. Many also used it to develop specific products. The organizations involved in the user-engagement activities differed greatly not only in terms of size, nature and their geographical scope but also in their sector of activity, planning and types of decision-making processes. Hence, their need for climate information also differed. Some sectors were more concerned with the impact of extreme weather while others focused more on variables such as temperature and precipitation. Since the RESILIENCE project is operated under the framework of energy sector, the results discussed in this report will also be focused on the lessons specifically applicable to the energy sector.

Energy sectors are more concerned with the variations in temperature, wind, solar radiation and precipitation that affect both energy production and consumers' demand. Weather forecasts were used to understand future weather conditions and plan activities. This information was generally provided either in the form of model outputs or as weather warnings, which were then translated into potential impacts. Historical data were largely used to understand potential weather variability and its impacts on production and consumption. For example, they were used to analyse how the organization's resources and infrastructures coped in the past when facing particular weather conditions and then plan accordingly.

In general, the timescale of climate information required depended on the planning of the organizational activities. Shorter time-scale were associated with day-to-day operations such as implementation, maintenance and monitoring, which occurs either daily or within the month. Majority of the organisations used predictions with lead times of a month up to a season. S2S forecasts were mainly used for operational tasks such as energy trading. Mid-term planning of activities (from 1 year up to 5 years) mostly related to business strategies, often linked to annual capital investment plans. In many cases, these activities are the strategic framework for more specific plans within the organisations. Others also planned maintenance activities and asset management within this timeframe.

Besides seasonal predictions, decadal predictions are also emerging. Although it is still in its infancy period and not many examples of active use in European context is found. Still, the participants expressed their need for decadal data (10 to 20 years) mostly for infrastructure development with regard to potential flooding and heatwaves. Long-term (from 5 years up to 30 years) time-scale prediction were mainly associated with wider vision and strategy, which relate to the resources and capital investment for the whole organisation within the energy sector mainly referred to such long-term planning.

In Europe, S2D climate products are still taking the first steps particularly regarding the practical use of this climate information to inform decision making. A general interest in customized SCPs products was perceived from the SPECS workshop that focused on the wind energy sector. While the visibility and thus, the demand for seasonal climate products are still low in this sector, the users saw a potential range of applicability in asset management, energy security, and interplay with hydro resources and in price negotiations. The more interested users in the economic potential of seasonal prediction were wind resource assessment consultancies, who saw seasonal wind speed predictions as a complementary service in their portfolio.

Wind farm developers were more accepting of the new methodologies for resource assessments and site-selection. However, the current development of climate predictions is not mature enough for them. There were also concerns regarding the quality of the forecast and whether its predictive capacity outperformed current practices. This led to some reluctance among users to include seasonal wind speed predictions as an information service for their professional activities. Nevertheless, there remains an opportunity to develop climate service ideas as there was a general agreement among the participants on the interest of being informed and on conducting review of seasonal predictions every 6 months. The wind industry outlook forum was targeted as a baseline effort to start building a network of users and providers of S2D information for the wind sector.

To summarize, based on the user-engagement activities carried out, the most common user needs in climate services for energy sector were identified as follows:

a. Precipitation data (both extremes and average; most demanded and most uncertain data)
b. Temperature data (as inputs for models)
c. Wind, storms, snow, humidity and cloud data
d. Solar radiation (especially DNI for solar energy)
e. Output of impact models (mainly hydrological)
f. Methods to deal with uncertainties in the data
g. Data beyond climatic data such as land use and sociological data

3.2. Forecasts Interpretation/Usability

It was quite evident from the user-engagement activities that the available and requested information was not adequate, climate variables were not reliable and climate information products were not always relevant to its users. The main barriers and limitations to the use of climate services as pointed out by the users revolved around the following issues:

3.2.1. Capacity and Relevance

Limited resources and capacity of both users and producers was considered a major source of barrier to the use of climate services. For users, it could mean lack of access to the observed historical data or other types of climate information they might require. It could also limit their ability to process raw data to fit their specific needs. On the other hand, it also limits the ability of the producers to provide the users what they actually require. Participants agreed that there were no products available at the moment that could fully satisfy their needs. Most of the interviewees also agreed on the need to address the diversity of user profiles because even within the same organization varied climate information were required across departments. Consequently, this led to new contacts and meetings with users from different departments who had a different perspective regarding the relevance of temporal/spatial resolution and climate variables.

Another lesson revealed was that near-term seasonal forecast products can be directive but may not necessarily be able to confirm a decision making process. There is still some development work required to build a bridge between seasonal prediction technology and industry stakeholders. Experimental usage by advanced users within the wind sector has been encouraging to the producers and can open the floor for more systematic usage. Tailoring climate information towards the specific needs of the users allow them to gain the ability to exploit and thus, demonstrate the benefits of climate services. This helps raise awareness of the advances within the field and their possible application and utility.

Thus, to stimulate a market for climate services it is necessary to identify the areas where climate predictions can improve decision-making processes and convey the utility of specific services in the effectiveness of users' day-to-day work. To this aim, participants suggested the need for co-production and co-generation of services, products and support to improve interactions between users and producers and thus, increase relevance of climate products. Such knowledge exchange can be facilitated through various engagement events and collaboration projects. Overall, the need for new and improved interfaces between users and producers was recognized.

3.2.2. Skill and Predictability

The development of SCPs has been evolving in recent years. Although skill and predictability differ across different regions, the likelihood of using current tools is limited, due in large part to the limitations in predictive skill of the forecasts. The participants in the SP4Wind workshop stated that they would only use the seasonal wind forecasting tool if and when seasonal wind prediction data becomes more skillful. There is also a need to understand the difference between perceived and real accuracy of climate predictions. The use of probabilistic forecast information requires an evaluation of the corresponding risk and the economic cost for a range of possible decisions that are specific to a climate-sensitive sector.

Hence, in order to establish user trust, the quality of seasonal products needs to be assessed more comprehensively. Relevant information such as verification of forecast skill must also be provided to the users of climate information. Improving models by investing in research and development, sharing guidance and case studies from peer products as well as clearly informing users on the limitations and assumptions were suggested as possible solutions to overcome the barrier to skill. Other suggestion included the need to move away from using traditional deterministic approach to forecasts, using indices rather than forecasts only and devising predictions for relevant variables. Education and training for both users and providers to understand the scientific and physical processes behind the lack of skill was also recognized as a possible solution.

3.2.3. Accessibility and Communication

Lack of relationship between end-users and providers means lack of awareness on part of the users on what is already available. Difficulties in accessing data and lack of interface can block the users from knowing and using climate service information. In addition, many users need to process the raw climate data into their operational models. However, little information exists on which methodologies to use and/or best practices while post-processing climate data. In general, tools to exploit the forecast information and guidance support to users are also limited. This can lead to misinterpretation of complex scientific data and reduce trust in climate services.

There also seemed to be lack of clarity in definitions and terminologies as well as in the timescales of climate predictions. For example, end users assumed that climate projections and climate predictions show the same information. Likewise, there was a general consensus that each FCs use different techniques to communicate climate information, which was confusing to the end users. The legend, units, longitude and latitude labels were not always included. If they were included, they were not consistent across FCs or clearly defined. The participants agreed that the graphics were difficult to understand and required explanatory information. The titles did not always explain the graphic well and the terminology was considered ambiguous (for example; acronyms or correlation of which variables). The choice of color was generally accepted, although the meanings of colors were often not clear. Recurring aspects of visualization such as standard forecast type and verifications were not presented in a common layout which lowered readability.

Forecast uncertainty and the role of verification data are also poorly understood by the end users. While users are aware of uncertainties in the data, they are unclear of how to deal with it. Some organizations compared forecasts from different sources to deal with uncertainty while some other required at least 70-75% of probability to make use of the information. Participants preferred methods for representing the uncertainties in numerical estimates to be able to quantify and integrate the information in their existing models. Other methods of representing uncertainty included the provision of data in a easy format and already interpreted for non-specialists.

Developing better data portals for sharing and disseminating information, promoting knowledge exchange events, along with good illustrations, factsheets and graphical presentations were recommended by participants to overcome barrier to accessibility and communication. Explanation of forecast terminologies as well as labels and grids should be consistent among FCs. Self-explanatory title should be used detailing the variable, forecast period, issue date, units, legends and target regions. Explanatory texts must be provided to clarify how to read/interpret graphics and colors. Color choices should be standardized across FCs to know which tercile is normal, above or below normal and represents which climate variable. Translation to English was also considered important for wide dissemination of information.

Thus, there is an on-going need to present the climate information results in a more user-friendly format catered towards users from non-scientific background. Decision-makers from various climate-sensitive sectors can benefit from improved accessibility, communication and understanding of climate forecast products.

3.2.4. Human Aspects to Decision-Making

Another barrier to the use of climate information in decision-making is reluctance among stakeholders to change existing working practices and protocols mainly due to the perceived risk. For example, the insurance sectors do not use S2D due to reluctance in breaking with existing practices. Many industries follow each other but none are keen to make the first move towards a new accepted standard due to perceived risk of doing things differently.

Also, the outcome of the decision making exercise, where each group were assigned a task to interpret the forecast and verification graphics revealed the human limitations of using complex scientific information. Some, not all, groups were given forecasts from the same FCs. However, all groups had forecast for the same variable and the same time period. Based on the information provided to them, some decided that the probability was not high enough to include the forecast information in decision making. Another group who were not given verification data decided to take caution against possible drought condition next season instead. Thus, a whole range of decisions were taken which highlighted the fact that individuals interpret information very differently and have diverging expectations. Hence, there is a need to consider human factors such as personality measures and the amount of risk an individual is willing to take. Analyzing risk management approach of end users should also go hand-in-hand with decision making processes using climate forecasts.

In addition, numerous visible sector rules are required to endorse subsequent decision making. Experiences gained from publicly available test cases can facilitate assessment and provide reference for real world usage. Further contacts with stakeholder must be maintained with special effort placed on obtaining feedback from use of climate information.

3.3. Forecast Visualization

The results of the user engagement research justly highlighted the need to make fundamental changes to improve the accessibility and communication techniques of forecast information. To this aim, ARECS, the climate services visualization interface was built to communicate seasonal climate forecasts to the energy industry users through visual application. Normally, visualisation researches in science and engineering disciplines tend to focus on ‘utility’ and ‘soundness’. However, design contributes further attention to the ‘attractiveness’ aspect, which can enhance legibility and cognition.

Participants were given a climate service web-tool for evaluation and feedback from a visualization perspective. The potential of offering visualization of data in portable electronic devices was self-evident and many started to browse the website on their handhelds. While participants indicated that they understood the information mostly, several ambiguities came to light when probed for their understanding of the data presented. In general, they understood most of the legends, although some voiced uncertainty about what they denoted. Most participants understood the terminologies but there was some ambiguity in their understandings. Participants generally found skill levels difficult to interpret and make decisions with. For wind predictions, participants recommended changing the display unit from KW to MW. They noted that the tooltips were useful and informative. Several participants suggested additional functionalities. Some visualization aspects required further explanation, suggesting areas of improvement. Casa dos Ventos (a Brazilian company) recommended the use of months instead of season given that the visualization of global prediction included the Southern hemisphere as well. Opacity was an issue for people with colorblindness as they would mistake the changes in opacity as changes in colour.

The success of online visual interface for communication of climate information illustrates the contribution of designers, who act as brokers and intermediaries to effectively communicate complex and uncertain scientific data to the end users. The designers need to learn and discover and be able to work alongside disciplines in which they are not an expert. They need to understand not only the data but also the values and priorities of the client as well as issues such as how uncertainty is communicated. Such user-centred design can then ensure that the final outcomes are useful, usable and likely to be used. For example, initially, the participants found it difficult to answer how *useful* the prototype as a tool (not the data) was because it was hard for them to separate the prototype from the seasonal prediction data, which lacks considerable forecast skill. With additional probing, they were able to conclude that the prototype was, on average, intuitive and easy to use (usability). However, they would use it only if the seasonal wind forecasts become more reliable (likeliness to use).

The participants added that the tool can also be used to make decisions related to energy trading, wind farm investment and maintenance. Participants recommended developing a new iterations for both supply (of which wind is an indicator) and demand (of which temperature is an indicator) once the data gap is addressed. Another suggestion was to explore the potential for commercial development when higher quality forecasts become available. This illustrates how in situations of complex domains and emerging markets, the additional attention to the front end of the design journey can help elicit requirements for a product that the user may not have previously considered. This provides a basis for future opportunities through enhanced clarity of complex information.

Visually representing probabilistic information can entail a compromise between scientific soundness, functionality and aesthetics. Therefore, it demands an interdisciplinary approach that brings together scientists, users and designers. Such teams need clear contexts of collaboration and sufficient learning time to allow mutual understanding. Public trials and demonstrations targeted to the right audience can facilitate development and testing with a wide range of user groups and help build the climate services market. Finally, it is also important to note that due to the enormous complexity and novelty of the climate services field, it is not always possible to meet user expectations or fully answer their needs. Yet, based on the learning thus far, a sincere recommendation to encourage the use of climate services for decision-making is to build a well-structured dissemination and engagement strategy that is executed through different communication and discourse channels as well as with the direct involvement of potential users in all stages of prototype co-creation.

4. Conclusions

To conclude, climate service products tailored to fit the need of end-users from various sectors can increase the potential to improve human resilience to climate variability and change. Although the skill to predict climatic conditions over Europe for various time scales is comparatively low, there has been promising advances in the science behind climate predictions. This has opened new doors of opportunity for climate information services. For example, while decadal predictions are still an emergent area of research, demand for SCP has been growing due to its improved skill.

Climate Services is a relatively new domain and many factors remain unknown. There is also low awareness among non-scientific users regarding relevant climate service solutions. The barriers are mainly due to low and uneven skill of prediction and lack of communication between producers and users, both of whom face time and cost constraints. In addition, there exists an informational challenge where the interpretation, use and adoption of complex scientific data is not straightforward. The end users are often neglected from the production and evaluation process of climate services and thus, there remains a gap between scientific data available and the actual information needed by the decision-makers.

It is essential to engage end-users in every stage of climate service development because as the final users their input can improve the design and usability of the climate service products and tools. First, to identify the domain and the problem, wide-ranging engagement between scientists and industry stakeholders is required to fully understand user needs. Secondly, knowledge from different disciplines, joined in interdisciplinary teams, is needed to communicate climate prediction data so as to avoid misinterpretations. Finally, design researchers can also bring their own expertise to build a human-centered visualization interface that can effortlessly communicate climate service information. Such collaboration of climate scientists, communication specialists and design researchers can improve the usability of climate predictions, tailor climate information to actual user needs and better communicate information.

BSC's collaboration with the RESILIENCE project aimed to engage various industry stakeholders to understand user needs and then build prototype climate services. A tangible outcome of these efforts was the ARECS, which provides seasonal climate predictions through an online web interface. This report summarized the various user-engagement activities that led to the development of ARECS as well as the activities that were undertaken by RESILIENCE to perform the evaluation of its efforts in facilitating user needs. The initial set of activities were focused in understanding who the potential users of climate services are and what climate information they actually need. In addition to traditional approach of systematic literature review, various user-engagement activities such as surveys, interviews and workshops, were also carried out to meet this objective.

Other user-engagement activities focused on the usability and interpretation of climate service products. Climate service data are complex scientific information and not readily interpretable or usable. Users were asked to evaluate how easy it was for them to access climate service data from various platforms and if they were comfortable using that information for decision-making purposes. Finally, the user-engagement activities were also carried out to focus primarily on building visualization interface that encourages end user to utilize and promote the use of climate service products. Stakeholders from energy sector were involved in these user-engagement activities whose expertise greatly offered to the development of ARECS. Communication specialists and visual designers were also engaged so as to learn the best way to transform complex scientific information into useful products with the aid of simple, attractive visuals, while also avoiding any misinterpretations by the end users.

Invaluable lessons were learned through this process. Climate services were mainly used to improve management of organizational activities that increased efficiency of products and outputs. Weather forecasts were the most used type of information. While users were reluctant to use seasonal forecasts information, they remained interested in being informed of advances in the skill of seasonal forecasts. Specifically in the wind sector, this interest led to a bi-yearly wind industry outlook forum, which was targeted as a baseline effort to start building network of users and providers of S2D information for the wind sector. Decadal forecasts were unchartered territory with only a few interests, mainly related to long-term planning. Historical data was largely used to understand potential weather variability and its impacts on production and consumption.

While there is no doubt that there is need for climate services, there are however many barriers to overcome. Being relatively a new domain, both producers and users face time and cost constraints. This limits the access of users to the climate service information and limits the ability of producers to understand user needs. Participants agreed that their needs varied and no single product at the moment fully served their specific need. Thus, there exists a gap between the scientific data available and the information needed by decision-makers. It is therefore critical that the scientific community developing S2D climate predictions engages with the users in order to better understand their current needs and inform the development of more adequate and usable data in the future.

The lack of deterministic skill, the marginal value of this type of forecasts and the need to better understand the value of probabilistic forecasts were also recognized as barriers to the use of climate information. For example, users are often aware of uncertainty in probabilistic forecasts but are not sure how to deal with them. This makes users reluctant to use climate information in decision-making. Thus, improving models by investing in research and development, providing, relevant verification information, sharing guidance and case studies from peer products as well as clearly informing users on the limitations and assumptions are possible solutions to overcome the barrier to skill.

On the other hand, even if the prediction skill is high, there remains a barrier of accessibility and communication. Due to the lack of relationship between end-users and providers, users are not aware of what information is already available. The complexity of this scientific information often means, they are not tailored to specific user needs. Thus, end users (especially with non-scientific background) often misinterpret the data and/or have to post-process data to fit their needs. This creates further confusion and decreases usability of climate service products. There is also wide consensus among users on the need to adapt a standard protocol among various FC while communicating climate information. For example, definitions, terminologies and recurring aspects of visualization must be clear and consistent. Developing better data portals for sharing and disseminating information, promoting knowledge exchange events, along with good illustrations, factsheets and graphical presentations were recommended by participants to overcome barrier to accessibility and communication.

All this suggest an urgent need to improve the communication of climate forecast information to the decision-makers. Improving the quality of the forecasts and synthesising the data to meet specific needs are some essential ways of creating better relationship between scientists and decision-makers. Establishing climate centres with advisors, who know the subject and have connections to climate scientists/institutes/universities, was a recommended solution to help translate the information accurately. Such centers can carry out training sessions for accurate interpretation of probabilistic information and create connecting links between forecast providers and users and ensure clarity of user needs and forecast information among both groups. Research that brings together these themes could help to greatly advance the use of climate forecasts in decision making processes, to facilitate the adaptation of key sectors of society to ongoing climate variability and the corresponding risks.

Overall, an interdisciplinary teams of sector-specific users, climate scientists, communication specialists and design researchers is highly recommended in all stages of climate service development in order to increase the resilience of the European society to climate variability and change.

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