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Sectoral use of climate information in Europe: A synoptic overview

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ABSTRACT

Society can benefit from usable climate information to better prepare and adapt to the risks and opportunities posed by climate variability and change. An adequate and effective provision of climate information – from historical observations through to seasonal forecasts, and multi-decadal climate change projections – is critical to inform planning and decision-making in climate-sensitive sectors. Central to this are the end-users of climate information and a growing emphasis on tailored climate information and services shaped by user needs. However, knowledge about the use of climate information across European economic sectors is limited. This paper identifies the spectrum of sectoral information requirements across a number of sectors including agriculture, forestry, energy, water, tourism, insurance, health, emergency services and transport sectors, drawing from an online survey (n = 462) and interviews with (potential) users of climate information (n = 80). This analysis reveals shared opportunities across sectors including the potential application of decadal climate predictions. In addition, common barriers and enablers to the uptake of climate information were also noted including the format of the information provided, the need for compatibility with existing in-house systems, and the perceived credibility and trust of information providers. This analysis also points towards a perceived increasing fragmentation of available information and the desire amongst end-users for a European body able to centralise and coordinate climate data. We highlight some of the current factors that still need to be adequately addressed in order to enhance the uptake and application of climate information in decision-making across European economic sectors.

Practical Implications

Access to useful and usable weather and climate information can help societies to better prepare, mitigate and adapt to the risks and opportunities posed by climate variability and climate change. Advances in observation networks, data processing and computer modelling have led to an expansion of available weather and climate information, from historical observations through to seasonal climate forecasts, decadal climate predictions and multi-decadal climate change projections. However, the uptake of this information amongst climate-sensitive sectors (e.g. agriculture, energy, water, health) and how this information informs real-world decision-making is not well documented. Moreover, the focus on improving technological and scientific capabilities has meant that less attention has been paid to improving the fit and usability of climate information (and climate services more broadly) to suit different end-user needs, as well as the various spatial and temporal scales of decision-making.

In the context of efforts being made to develop a climate services market in Europe (EC, 2015), this paper provides a synoptic overview of the current use of weather and climate information across key economic sectors in Europe. On the basis of mixed methods research performed within the EU EUPORIAS project, this paper triangulates the findings derived from qualitative and quantitative analysis of 80 in-depth stakeholder interviews and 462 responses from an online survey.

The research documents the wide range of sources from which organisations obtain different types of weather and climate information. In turn, variations are observed in terms of the frequency at which different types of information are used and nuances identified between different economic sectors. As one would expect, there is a general trend towards the application of weather forecasts

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to inform operational day-to-day activities, whereas seasonal climate predictions and climate change projections are aligned to longer-term strategic organisational planning.

Interestingly, conflicting findings emerged in the context of decadal climate predictions which, whilst widely reported in the survey results, were not currently used by the organisations interviewed and were generally regarded as uncharted territory. Moreover, the term appeared to be misunderstood and misinterpreted (e.g. as synonymous to climate change projections or akin to forecasts for the next decade). Although this somewhat limits this aspect of the survey data, it simultaneously highlights an important gap in understanding and need for improved communication across scientific-practitioner-policy communities. Nonetheless, the interviews revealed a clear interest for developing decadal climate predictions in practice, albeit further research is required including to help understand how these may be translated into usable products.

The research also sheds light on the reasons why some organisations are not using climate information. Whilst based on a smaller sample (n=43), these findings give some insight into the potential barriers to the uptake of climate information. For instance, with 37% and 23% of the sample stating that current weather and climate information is either not useful or fails to suit their needs, questions must be posed on how this information can be better tailored according to end-user requirements. Another important observation is that 26% cited a lack of in-house expertise which suggests that either there needs to be some form of organisational/institutional capacity building to address this expertise-deficit and ensure appropriate resources are in place, or alternatively information needs to be provided in a way that is compatible with existing processes and in-house systems.

Furthermore, the research findings challenge the general assumption that scientific uncertainty is unwelcome as many felt that it was an essential component of climate information. Although 67% of survey respondents (n=128) felt that they needed information to be presented in a way that will help inform binary (yes/no) decision-making, the survey findings also revealed that a wide range of formats for presenting uncertainty are currently used (including text descriptions, numerical estimates, maps and graphics). A preference was expressed by interviewees towards numerical representations of uncertainty whether by single figures, percentages or confidence intervals. In turn, this enables organisations to quantify uncertainty, integrate within existing model or inform graphics to help communicate uncertainty to different audiences (e.g. maps).

The nuances observed between sectors in the use of weather and climate information highlights the diversity of needs and requirements that make-up the complexity of the users' landscape. Rather than viewing the 'end-user' as a homogenous group, this research confirms the importance of stakeholder engagement to better understand and tailor the provision of climate information accordingly. However, there remain important gaps to be filled. In particular, there is a clear interest in the use of decadal climate predictions, yet these remain poorly understood and limited to research-based applications. Moreover, in the wider context of efforts to develop a climate services market in Europe, there is a need to address numerous barriers and promote i) better understanding of climate information, including its parameters, limitations and scientific uncertainty; ii) improved coordination and standardisation across fragmented sources of climate information and accessibility; and iii) address current gaps in provision.

1. Introduction

Access to useful and usable climate information is an important step towards building climate resilient societies, where the risks posed by climate variability and change are anticipated and mitigated, and potential opportunities maximised (EC, 2015; Street, 2016; Goddard, 2016). This realisation is fast driving efforts to develop and promote a climate services market in Europe and safeguard the provision of climate information to assist decision-making across numerous climate-sensitive sectors (e.g. agriculture, energy, water, insurance) (ibid; Lourenço et al., 2015).

However, efforts to date have tended to concentrate on improving the underlying scientific prediction or observation systems whilst less attention has been paid to improving the fit and usability of climate information for decision-making (Lemos et al., 2012; Kennel et al., 2016). Correspondingly, the extent to which climate information is used to support decision-making is not clear. To address this, more recent research efforts have sought to better understand the needs and requirements of the end-user, asserting the importance of stakeholder engagement to better inform and tailor climate information to parameters and formats that are user-relevant (Street, 2016; Buontempo et al., 2014). Given the multiplicity of end-users and diversity of decision-making (i.e. across sectors and spatio-temporal scales), this is by no means a simple task. Moreover, research is often fragmented and concentrated in sector-silos, thus a synoptic overview of the use of climate information in multi-sector decision-making is noticeably absent.

Addressing this gap, the EU FP7 funded project EUPORIAS examined the European provision of regional impacts assessments on seasonal to decadal[1] timescales (http://www.euporias.eu/) (Hewitt et al., 2013). As part of this project, a European online survey and in-depth stakeholder interviews were conducted to assess user needs of climate information, with a particular focus on seasonal forecasts and decadal predictions. Drawing from these data, this paper presents a synthesis of the commonalities and sectoral differences in the use of climate information across Europe. In turn, we reflect critically on the implications of these findings in terms of tailoring climate information to specific user-groups and improving its usability and uptake to inform decision-making processes.

2. Literature

Recent efforts in Europe have sought to improve the accessibility, availability and usability of climate information within the emerging context of a climate services market (EC, 2015; Street, 2016). This new landscape of climate services has been framed internationally by the Global Framework for Climate Services (Hewitt et al., 2012) and more recently in Europe by the Roadmap for Climate Services and the Copernicus Climate Change Service (EC, 2015).

Although a contested concept, the notion of climate services normally refers to the development and/or provision of climate information and knowledge to support users' decision-making through tools, websites, and tailored products (see e.g. Vaughan and Dessai, 2014; Hewitt et al., 2012). Central aspects to this concept are i) the 'users' of the service, ii) the climate information that is required by the user, and iii) the provision of climate services.

The 'users' of climate services represent a wide range of organisations (public, private and civil society) and actors (e.g. end-users, intermediary/purveyor organisations) occupying a multitude of institutional settings and with varying interests in the type of climate information they require to support a range of applications and activities. Consequently, user requirements

[1] Decadal and interannual climate predictions are regarded as interchangeable in this paper.

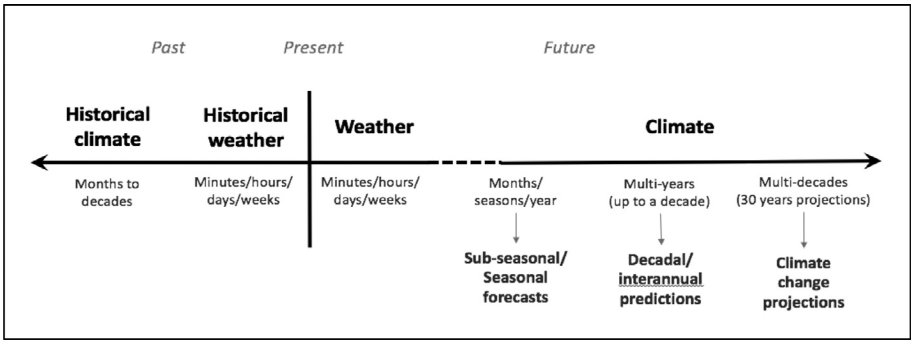

Fig. 1. Main typologies of weather and climate information.

span across a spectrum of so-called Essential Climate Variables (ECVs; see Bojinski et al., 2014), Climate Impact Indicators (CIIs; see EEA, 2012), raw data versus tailored products as well as various spatio-temporal resolutions (Bruno Soares and Dessai, 2015; EC, 2015). For an effective provision of climate services, there is a growing consensus that user engagement and knowledge exchange across traditionally divided scientific-policy-practice communities is essential (cf. Lemos and Morehouse, 2005; Hering et al., 2014). This standpoint is underpinned by wider theoretical discussions of the science-policy interface, advocating that applied science dealing with complex problems (such as climate change) should account for different types of knowledge (i.e. beyond technical/scientific frames) and, consequently, promote and facilitate opportunities for interaction and co-production of knowledge (Kirchhoff et al., 2013). In this light, the user is no longer conceived as the passive receiver of scientific information (as in the traditional loading-dock approach) but as an active participant in the knowledge creation process with valid expertise of the particularities of their decision-making context (Vaughan and Dessai, 2014).

Another intrinsic component of climate services is the climate information that is developed and provided to support the users' decision-making (Trenberth et al., 2016). This information can range from historical climate data to long-term climate change projections, as conceptualised in Fig. 1. Whilst some kinds of climate information have been available for longer, such as historical climate data and long-term climate change projections (EEA, 2012) others, such as seasonal climate forecasts, have only recently become more widely available in Europe (Bruno Soares and Dessai, 2016; Hewitt et al., 2013). Situated between seasonal climate forecasts and climate change projections, initialised decadal climate predictions represent a new type of information although still within the research realm as the skill of such predictions is currently limited (Smith et al., 2013). Adding to this spectrum of information are weather forecasts[2] which have been available since the 1950s (Shuman, 1989).

Similar to the complex landscape of users, the development and/or provision of climate services can also be pursued by a multiplicity of actors including National Meteorological and Hydrological Services (NMHS), private consultancies, research institutes, and even in-house development within organisations (EC, 2015). The supply of information to users can also be distinguished by different forms of provision e.g. public vs private services, raw model data vs user-tailored products. These chains of information provision can be constituted by different actors, including intermediary organisations (also known as purveyors) whose role is to make the bridge between those producing information (e.g. NMHS) and the end-users and/or to other purveyors (Vaughan and Dessai, 2014; Lourenço et al., 2015).

A comprehensive understanding of the users and their climate information requirements and needs, is essential for the development of useful and usable climate science – and in a broader context the overall development of effective climate services – that address real-world decision-making. However, to date few studies in Europe have focused on climate services providers and the climate information and tools produced (e.g. Máñez and Zölch, 2014; Banos de Ghisasola, 2014; Göransson and Rummukainen, 2014), or the climate information needs of the end-users (e.g. Dessai and Bruno Soares, 2015; Turnpenny et al., 2004). Addressing the latter, this research sought to provide a synoptic overview of the current application of climate information across different sectors in Europe.

3. Methods

Adopting a mixed methods design, this research draws from a European-wide online survey (n = 462) and in-depth semi-structured stakeholder interviews (n = 80) conducted between June 2013 and June 2014 under the auspices of the EUPORIAS project. Both the interviews and the survey sought to capture the climate information needs of users with a focus on the end-users (although the needs of some intermediary/purveyor organisations were also captured). Similar lines of questioning were pursued in both methods to provide a foundation for comparison and to enable the triangulation of research findings to corroborate and/or identify conflicting observations (Moran-Ellis et al., 2006; Gray, 2009). In particular, participants were questioned about their usage of different types of information (e.g. meteorological, climate, economic, environmental, etc.) in terms of frequency of use, source and types of organisational activities this informs. Attention was also given to the matter of data uncertainty, how this is managed and how often different representations of uncertainty are used. Equally important were the views of those not using climate information and the reasons for this, which were also examined through interviews and the survey. Finally, we sought to identify current gaps and other types of information that might be deemed useful.

Interviews were conducted with various organisations in Europe, purposively sampled to provide a range of views both within and between various economic sectors although energy, transport, emergency services, agriculture and water sectors are best represented in this study (Fig. 2). The survey captured a broader spectrum of viewpoints although again, transport and emergency services, energy and agriculture and water were the best represented amongst the economic sectors. Interestingly, the majority of survey respondents (n = 109) did not associate their organisations to these defined sectors, but associated their organisation with other activities, the top 3 of which related to i) environment,

[2] These refer to weather forecasts based on numerical predictions.

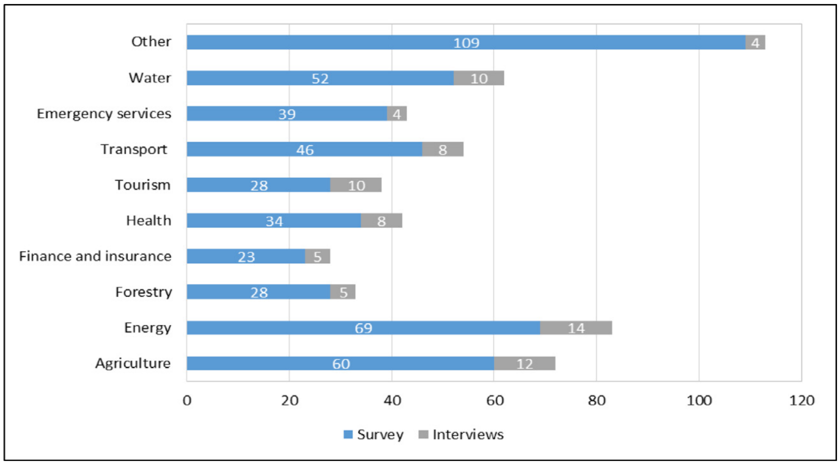

Fig. 2. Number of respondents per economic sector (note that multiple answers were possible).

conservation and heritage, ii) weather and climate change (such as NMHS and research institutes), and iii) industry, construction and materials. Furthermore, the majority of participants (both in the interviews and survey) represented generally large private companies and governmental organisations operating at the national scale. The geographical spread of the data is illustrated in Fig. 3.

Interview data was analysed in the qualitative data analysis software NVivo through the techniques and practices of thematic coding (Gibbs, 2002). Concurrently, survey responses were subject to descriptive analysis using the Statistical Package for the Social Sciences (SPSS) alongside some qualitative analysis of responses to open-ended questions within the survey. Due to the variable response rate across sectors it was not possible to perform statistical analyses to identify the presence of significant differences between sectors in their usage of weather and climate information. However, the sample was split between sectors to infer such

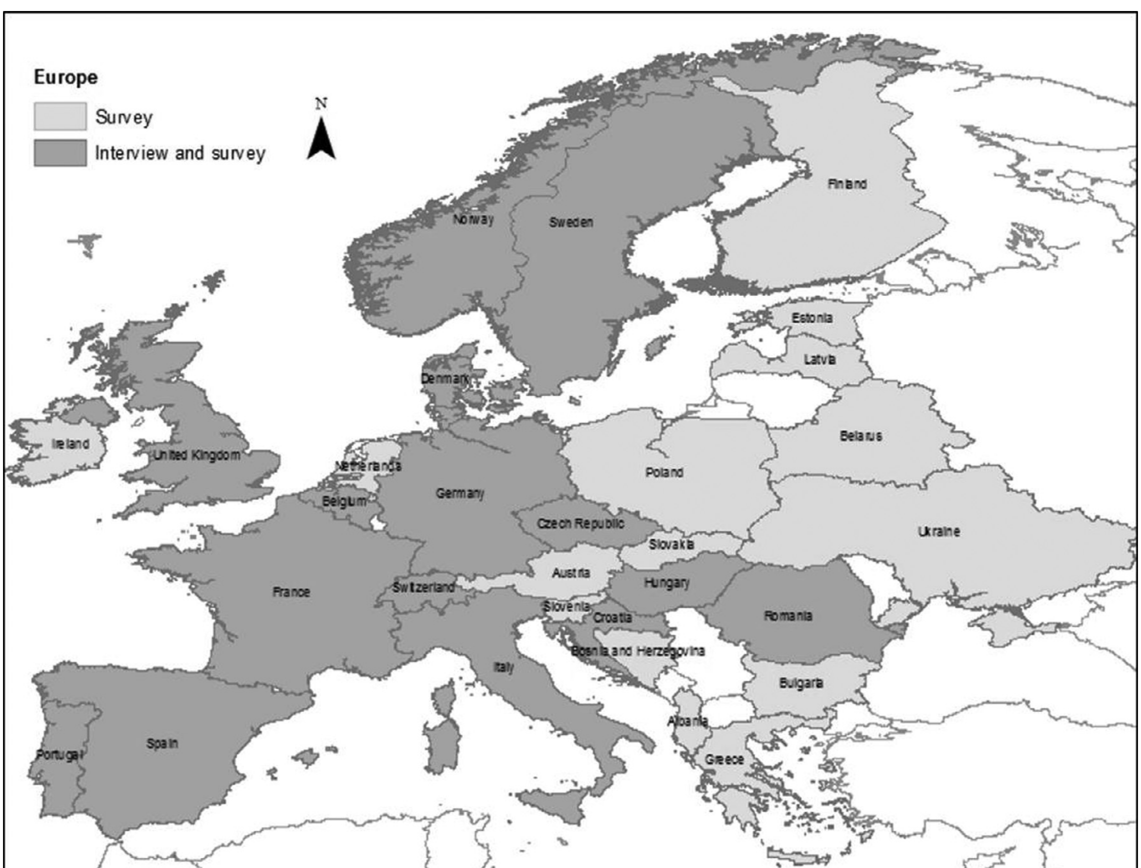

Fig. 3. Geographical distribution of survey and interview responses across Europe. *Six of the interviews conducted are not represented in the map as four of the organisations have several offices spread across Europe/worldwide whilst the other two interviews were conducted with organisations based in Africa. An interview conducted in the transport sector in Cyprus is also missing as the country was not represented in the original background map (Copyright © 1999–2010 ESRI Inc.)*

potential differences albeit from a more subjective standpoint. Bringing these insights together, this paper will now present a high-level synthesis of the research findings and overarching trends with regard to the current use of weather and climate information across European sectors.

4. Results

4.1. Sources and frequency of use of weather and climate information

The survey data shows that numerous types of weather and climate information are in use and sourced from multiple organisations (Fig. 4). In particular, forecast information and historical data, are largely obtained from NMHS. Second to this, government agencies and departments are the next biggest provider of information, closely followed by research institutes, particularly in the case of climate change projections, whilst the European Centre for Medium-Range Weather Forecasts (ECMWF) is also a main provider of seasonal climate forecasts. In contrast, a comparatively small amount of information appears to be generated and held internally by those organisations sampled.

The survey data also shows that although numerous types of weather and climate information are in use, climate change projections and decadal climate predictions are less frequently used in comparison to other types, particularly weather forecasts (Fig. 5). Also evident from the survey data are variations in the frequency of which different types of weather and climate information are used. Whereas weather forecasts are typically utilised on a daily basis, other forms of data tend to be used on a monthly basis (i.e. seasonal climate forecasts) or annual basis (namely decadal predictions and climate change projections).

A broad range of planning activities and decision-making processes are pursued by various organisations (Fig. 6). Therefore, the types of weather and climate information utilised is notably varied across the various temporal scales at which these activities are situated (as illustrated in Fig. 7). This observation was confirmed through the survey and interviews findings, albeit with subtle nuances between economic sectors as examined in the next section.

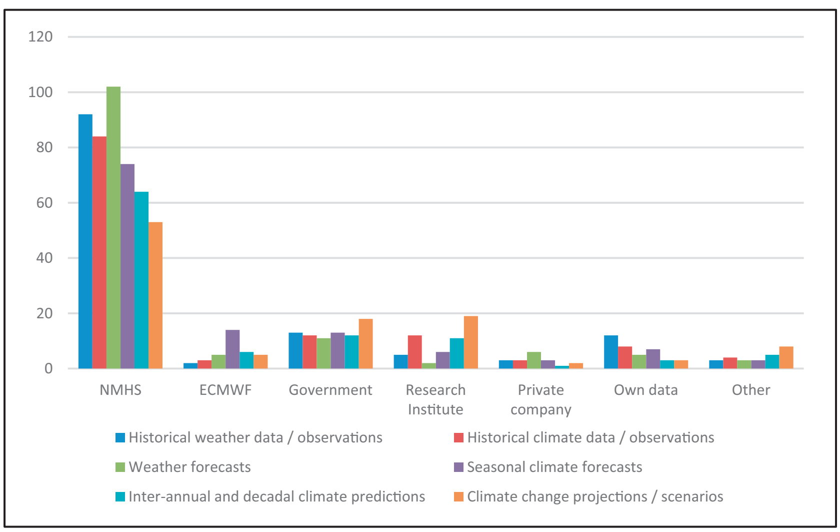

Fig. 4. Source of weather and climate information per type of data/information across survey respondents.

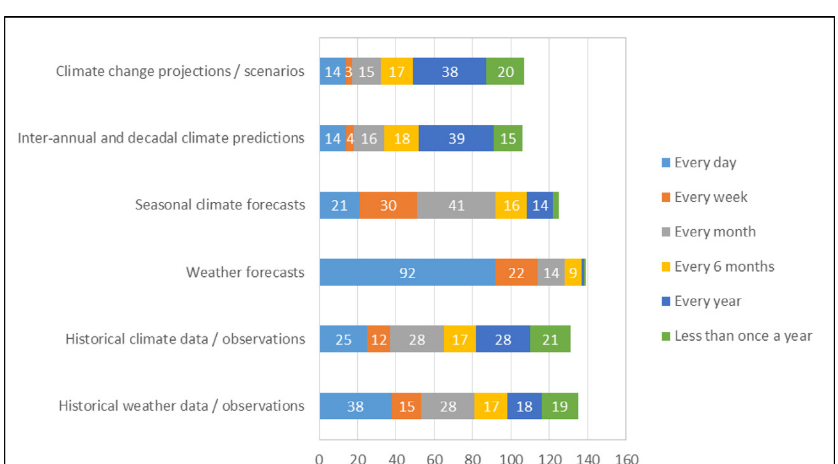

Fig. 5. Frequency of use of different types of weather and climate data across survey respondents.

4.2. Use of weather and climate information across sectors

Within the sectors studied fairly equal numbers of respondents are using different types of information (Fig. 8). However, across sectors the use of weather and climate information is higher amongst those outside the studied sectors (categorised as ‘other’ sector) as well as the agriculture, energy and water sectors (Fig. 8). The predominance of these sectors is possibly linked to the fact that many of the organisations surveyed were large organisations (43% of the organisations had more than 500 employees) which often have the necessary resources and capacity to allow them to use the information available (cf. Bruno Soares and Dessai, 2016). In addition, agriculture, energy and water sectors are also priority areas for research and development within climate services which most certainly have helped promote the uptake and use of climate information within these sectors (Hewitt et al., 2012; European Commission, 2015).

Overall, climate change projections and decadal climate predictions play the greatest role in *longer-term strategic planning*, closely followed by seasonal climate forecasts and past climate data (Fig. 9). On a sectoral level this pattern is variable (see Appendix A for a detailed comparison between sectors). In the energy, health and water sectors climate change projections are the most frequently used followed by decadal climate predictions. However, in the agricultural and forestry sectors it is the other way around (i.e. decadal predictions are more used than climate change projections) whilst both types of information are equally used in transport (see Appendix A). The exception to this pattern resides with the emergency services sector, where climate change projections and seasonal climate forecasts are equally used. However, caution should be exercised in extrapolating these results further given the low number of respondents representing this sector (n = 4). The third most common type of data used across sectors is either seasonal climate forecasts (agriculture, water and health) or past climate data (energy, forest and transport). It is noteworthy that past weather data is tied in third place with seasonal climate forecasts in the health sector, and is also the third most frequently type of information used by emergency services.

Drawing from the interview data, *long-term strategic planning* (from 5 up to 30 years) is often associated with strategic visioning

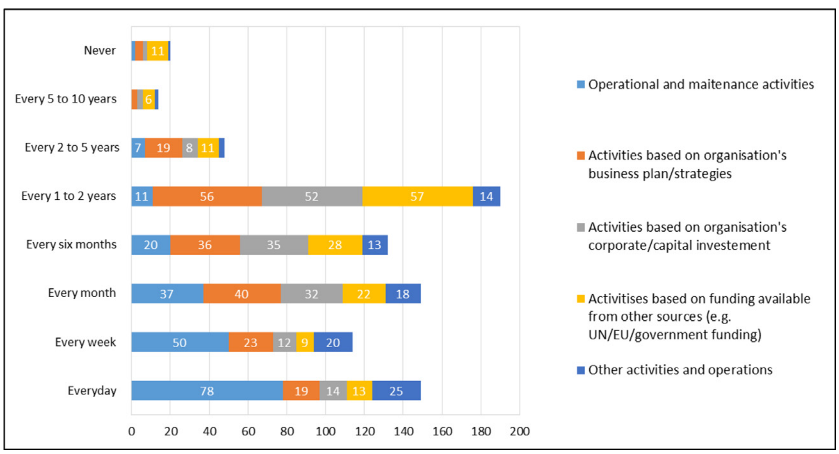

Fig. 6. Frequency at which main types of planning activities and decision-making processes are pursued across survey respondents.

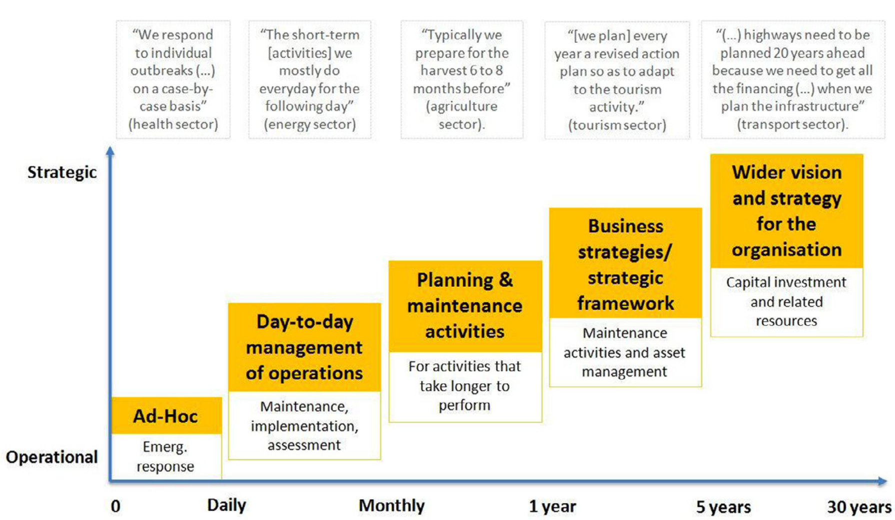

Fig. 7. Examples of planning and decision-making across timescales based on the interviews conducted (from Dessai and Bruno Soares, 2015).

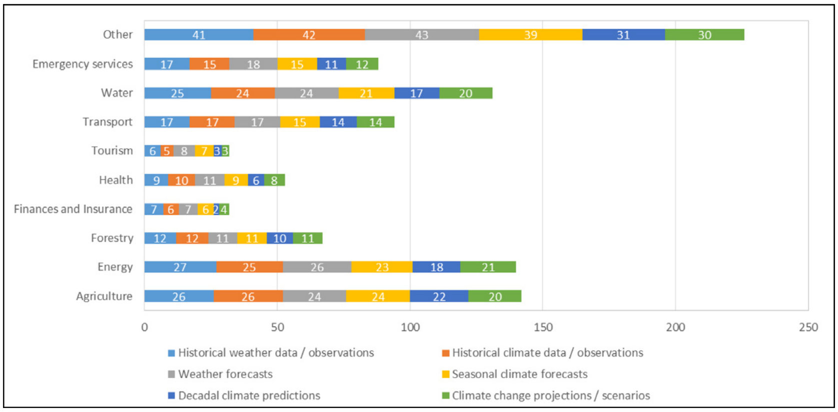

Fig. 8. Use of climate information across survey respondents per economic sector (Note that this was a multi-answer question).

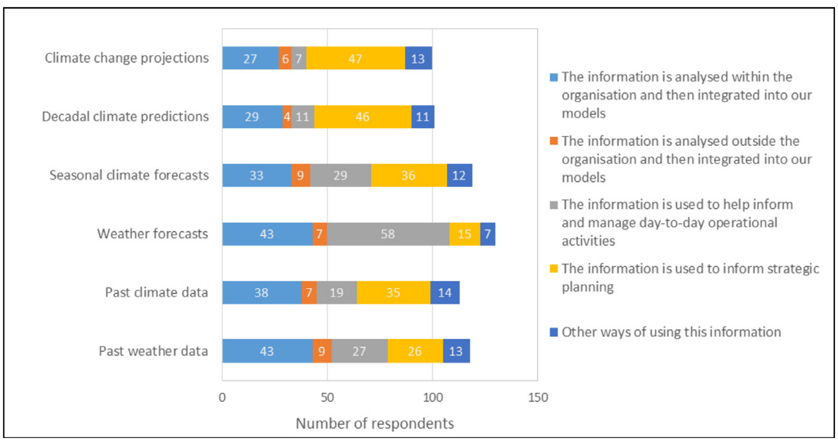

Fig. 9. Uses of weather and climate information in organisational activities based on survey results.

and capital investment decisions within the organisations. Similar to the survey findings, climate change projections also played an important role in supporting such *strategic planning* and decision-making particularly in some of the sectors studied. From the interviews conducted, 36% (n = 80) used climate change projections or scenarios, particularly in the 'other' sectors (100%; n = 4), water (70%; n = 10), health (63%; n = 8) and transport and emergency services (50%; n = 12) sectors. In the remaining sectors – energy, agriculture, forestry and insurance – the use of climate projections was comparatively lower. Also discussed during the interviews was the use of past climate and weather data (rather than climate projections) in *strategic planning* in the organisations (n = 38), as a means of understanding weather variability (e.g. via historical variability analysis) and predicting future conditions. In turn, this was shown to help organisations to infer potential impacts and implications for their activities and operations, such as energy consumption, or to help evaluate the resilience of critical infrastructure (e.g. transport networks).

Interestingly, whilst seasonal climate forecasts appear to be widely used amongst the organisations represented in the survey (Figs. 5 and 9) this represented the least used type of information amongst interviewees (only 25 organisations out of 80 used). The usage of seasonal climate forecasts is spread across interviewees' sectors although these were mostly used in the energy, water, transport and emergency services and insurance (cf. Bruno Soares and Dessai, 2016). However, such use was qualitative in nature (i.e. as a textual piece of information rather than as an input for existing models) and varied from supporting operational and strategic planning, to those simply using the information to provide a general picture on the potential impact of future conditions (for more see Bruno Soares and Dessai, 2016).

Similarly, decadal climate predictions appeared to be widely used in the survey but none of the organisations interviewed reported using this type of data and considered it to be unchartered territory (cf. Bruno Soares and Dessai, 2015). In fact, only one interviewee from the agricultural sector mentioned the use of decadal variability information in a qualitative manner to aid seasonal forecasting (i.e. the phase of the pacific decadal oscillation which affects the probability of occurrence of El Niño/La Niña).

Those aware of decadal climate predictions agreed that "(...) it is not well-known yet. It's not really available and I don't think we understand well the added value of using this kind of decadal climate information and the associated uncertainties." (Interview in the agriculture sector). Although none of the interviewees used decadal climate predictions many felt that this type of information could play a useful role in their planning and strategic activities particularly in the transport, energy and forestry sectors (n = 21). For example:

"(...) for many people it's difficult to perceive or to visualise 50 years ahead. So, if we had shorter term for scenario and climate scenarios, I mean not so much, so far in the future but closer to now, that would be very helpful. That depends of course who you talk to but, for instance, if we take an example of (...) politicians then something that would happen within ten years or so, it's much more, would be very helpful to be able to indicate." (interview in the 'other' sector).

"So if the science develops so that we can do very good, well credible decadal forecast or decadal forecast with some skill in some areas then that kind of information, I think, will be very useful. I think there will be a very big demand for that." (interview in the energy sector).

Weather forecast information was the most frequent type of information used across all sectors on a daily basis (n = 92, Fig. 5). As such, day-to-day *operational activities* are largely informed by weather forecasts (i.e. up to 1 month) (Fig. 9). In fact, across all sectors, *operational activities* are predominantly informed by weather forecasts, with the exception of the forestry sector where seasonal climate predictions are equally used. However, variations exist in the second most common type of information employed by organisations (see Appendix A), with seasonal climate forecasts in energy, health and transport sectors and past weather data in emergency services. In the case of the water and agricultural sectors, past weather data is tied in second place with past climate data and seasonal climate predictions, respectively (Appendix A) and tends to be used to infer potential impacts and manage operational activities, feed existing models and/or help with strategic planning (see Fig. 9). The interview process also confirmed the importance of weather forecasts, with 64% of the interviewees using this type of information to help them infer potential impacts to inform decisions and manage *operational activities* either in the form of model outputs or weather warnings. For example:

"We take real time weather information into national flood forecasting models, to understand the immediate flood risk and that would be done over a five day, a weekly period, looking out and then, issuing warnings (...)" (interview in the 'other' sector).

"We use weather information to make short term decisions related to harvesting and treatments, on a day-to-day basis. For example, you don't perform a treatment if it's going to rain this day or the following. The harvesting can be moved forward or backward depending on the rain forecasts. We use weather information there, but we don't use it in other sales-oriented decisions" (interview in the agriculture sector).

4.3. Integration of weather and climate information within organisations

Another application of weather and climate information is the analysis and integration of this data within existing models held internally by organisations (as opposed to being outsourced externally). According to those interviewed, the use of data in this way helps inform both *operational activities*, as well as *strategic-level planning and decision-making* (as previously discussed). Across the survey sample as a whole, weather forecasts and past weather data are reportedly the most frequent type of data subject to internal processing (i.e. post-processing activities), closely followed by past climate data and seasonal climate forecasts (see Fig. 9 and Appendix A). In addition, the use of weather forecasts, past weather data, past climate data and seasonal forecasts are largely linked to informing and supporting the day-to-day *operational activities* of the organisations although the use of past climate data and seasonal forecasts also help to inform *strategic planning* (Fig. 9).

On a sectoral level, there are some variations in this pattern (displayed in detail in Appendix A). Past weather and climate data are equally used in agriculture and health sectors, and further tied with weather forecast data in the water sector; whereas past weather and climate data is secondary to weather forecasts in emergency services. Weather forecast data and past weather data are equally used in this way in the energy sector, followed by past climate data. Interestingly, seasonal climate forecasts and then climate change projections, decadal climate predictions and weather forecasts (tied in second place) are used in the forestry sector in this way, making this a unique case. Decadal climate predictions are also the second most used type of data in the agricultural sector. Amongst the organisations sampled within the transport sector, past climate data is the main type of data integrated into internal models, followed by past weather data, weather forecasts and seasonal climate forecasts (equally tied). Seasonal climate forecasts are also the second most type of data used in this way amongst the water and emergency services sectors (Appendix A).

In a relatively smaller number of cases, some weather/climate information is outsourced to external companies for post-processing and analysis before being integrated within internal modelling software (Fig. 9). This was reported in most sectors, particularly forestry, as well as energy, agriculture, transport, water, emergency services and one case in tourism. No examples of this were evident within the health or insurance sectors sampled as part of the survey.

Some respondents also described additional uses of weather and climate information. This included specific details on i) operational tasks, such as decisions about tree planting (choice of species and location) in the agricultural sector; ii) research activities (n = 3); iii) data analysis and processing to inform decision-making (agricultural and water sectors) or analyse internal indicators (insurance); iv) dissemination activities with media or other organisations (n = 4); v) regulatory reporting to assess return periods of rainfall events (water sector); vi) inform weather warnings; and vi) develop standards and guides on the use and interpretation of information and data (e.g. World Meteorological Organisation).

4.4. Non-use of climate information

Equally important to understanding the use of weather and climate information are the reasons why some organisations are not using climate information. This was addressed in the survey through a series of statements against which respondents stated their level of agreement (Fig. 10).

Of the organisations currently not using weather or climate information (n = 43) the main reasons presented were the lack of usefulness of weather or climate information in their organisation (n = 16), the lack of in-house expertise to use the information (n = 11), and the lack of suitability of existing information to match their needs (n = 10).

These figures give some insight into potential barriers to the uptake and use of climate information. With 37% and 23% of the sample stating that current weather and climate information is either not useful or fails to suit their needs, questions must be asked about how this information can be better tailored to end-user requirements. Another important observation is that 26% cited a lack of in-house expertise, which suggests that either there needs to be some form of organisational/institutional capacity building to address this expertise-deficit and ensure appropriate resources are in place, or weather and climate information needs to be provided in a way that is compatible with existing systems,

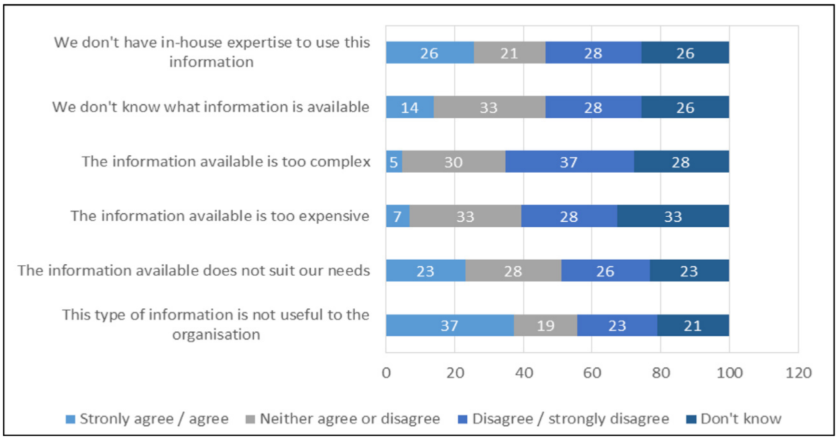

Fig. 10. Reasons for not using weather and/or climate information (results based on valid percent, where n = 43).

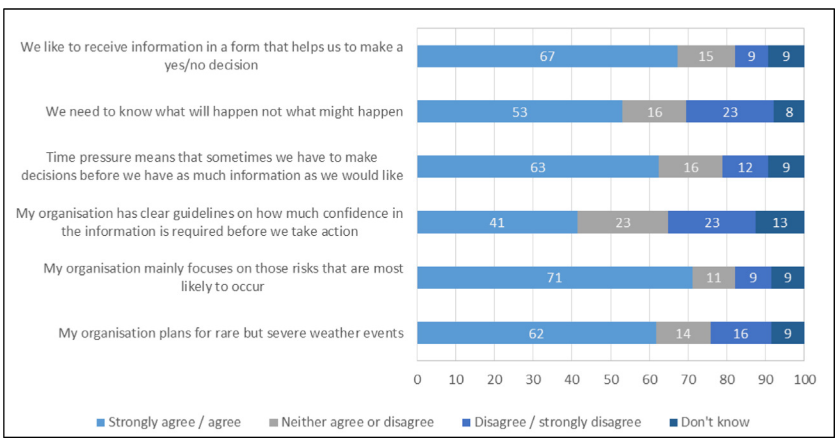

Fig. 11. Respondents' levels of agreement with uncertainty-related statements(based on valid percent, where n = 128).

or at least less burdensome to existing organisational arrangements. There is also an issue relating to awareness (or lack of) amongst 14% of respondents, implying a need for better advertising and promotion of existing climate information, increase accessibility and facilitate integration into existing decision-making processes.

Whilst these numbers are based on a limited sample, it is nonetheless useful to help pinpoint potential barriers (and enablers) to the uptake and use of climate information in sectoral decision-making. Similar observations have also been reported in the literature (see e.g. Lemos et al., 2012; Feldman and Ingram, 2009; Bolson and Broad, 2013). Enriching these findings, the interviews shed further light on the factors facilitating or hindering the use of climate information in the organisations (see Bruno Soares and Dessai, 2016). For example, the most common enabling factor for the uptake and use of seasonal climate forecasts amongst those organisations interviewed were existing relationships with the providers of climate information (mainly NMHS). Conversely, the lack of perceived reliability[3] was the main barrier to the use of seasonal climate forecasts.

[3] The term *reliability* is used here as a synonym of (perceived) trustworthiness and, as a result, it can be mapped onto a number of other technical concepts such as *skill*, *reliability*, and *sharpness*.

4.5. Handling uncertainty

To determine attitudes towards scientific uncertainty, the survey employed a series of statements against which respondents specified their level of agreement (Fig. 11). Whilst 62% organisations represented in the sample plan for rare but severe weather events, 71% also focus on those risks most likely to occur. Only 41% have clear guidelines specifying the level of confidence required before certain information should be taken into account. However, time pressure can mean that organisations must sometimes make decisions without having as much information as they would like (63%). In just over half of the cases (53%) respondents declared the importance of acting on certain information (i.e. 'need to know what will happen not what might happen'). Interestingly, 67% of respondents felt that they needed information to be presented in a way that will help inform binary decision-making (yes/no).

The survey also examined the format in which uncertainty information is typically represented and how frequently these are used by the organisations (Fig. 12). Across the different categories there appears to be an almost equal division in the use of text descriptions, numerical estimates, maps and graphics.

Qualitative analysis of interview data further enriches these observations. Amongst interviewees, scientific uncertainty was generally recognised as an unavoidable but essential component

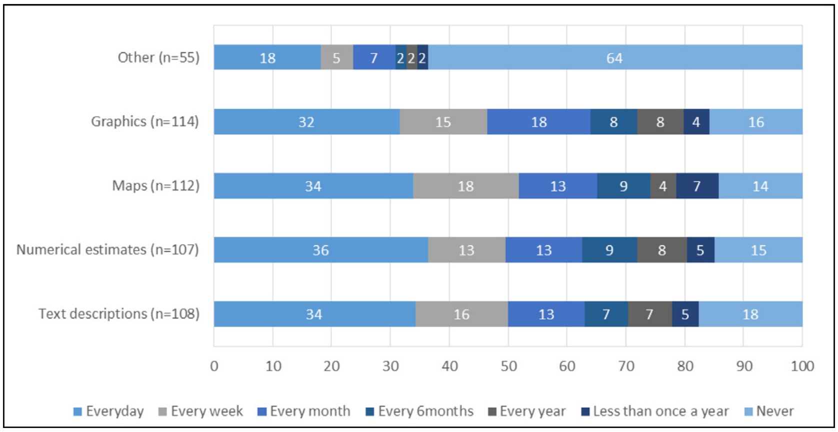

Fig. 12. Use of different formats for representing scientific uncertainty in climate information (based on valid percent of respondents, as derived from survey data).

to climate information. However, across sectors confidence thresholds related to what is deemed acceptable for use have emerged to handle this uncertainty in the decision-making process. As expected, the highest probabilities are desired and few of the organisations interviewed specified a guideline minimum of 70–75% (8 out of 80). A specific case was an organisation in the agricultural sector which specified 67% reliability 'as a rule of thumb'. Reliability estimates below 50% were generally disregarded by the users interviewed. Although based on a small number of cases, these interviews provide an important insight into the variably institutional attitudes towards risk.

> "If the uncertainty is very high, we won't obviously consider the climate information to make any decisions. For instance, according to my experience, if it is said that it is going to rain with 40% probability then I don't consider that information at all, it is worthless in a drought period" (interview in the insurance sector).

A preference was expressed by interviewees towards numerical representations of uncertainty, whether by single figures, percentages or confidence intervals. In turn, this enables organisations to quantify uncertainty, integrate it within existing model or inform graphics to help communicate uncertainty to different audiences (e.g. maps). With regards to visualisations, some organisations felt that these would need to be accompanied with descriptive or explanatory statements to facilitate understanding amongst less experienced audiences. Overall, there was a consensus that, ultimately, the representation of uncertainty should fit the needs of the user.

> "It depends on who uses it. Traders who permanently must make quick decisions like visual displays or one-sentence messages. They like very clear, simple graphics which allow them to capture immediately and understandably all the relevant information. Crop analysts on the other hand, really need numbers and more detail." (Interview in the agriculture sector)

In contrast to the widely view that scientific uncertainty is unwelcome (e.g. Faulkner et al., 2014) these findings demonstrate organisational concern with the representation of information and willingness to embrace uncertainty.

5. Discussion and conclusions

This study highlights the range of weather and climate information that are applied in practice across different economic sectors in Europe. Weather forecasts were the most prominent type of information used across all sectors and play the greatest role in informing *operational activities* in the organisations' decision-making. In part, this reflects the need for timely information (particularly regarding shorter timescales such as weather forecasts) with higher levels of (perceived) accuracy than other forms of information bounded by longer time horizons (e.g. seasonal climate forecasts and climate change projections). There is also an established culture of using weather information related to their longstanding existence and availability in Europe as well as their provision through NMHS (WMO, 2015; Zillman, 2005). Past weather and climate data are also widely employed alongside weather forecasts to help infer and predict future climate conditions. These types of information appear to have become mainstreamed in organisational activities.

In contrast, the application of less-established and emerging types of information is varied across sectors. Seasonal climate forecasts and climate change projections are more commonly used in agriculture, energy, water and 'other' sectors of activity (including the environment, weather and climate change, industry and research sectors). Based on the interviews' data, the prominence of climate information use amongst these sectors appeared linked to the size of the organisations involved in this study and their existing resources and capacity which, allied to their market driven approach (as many were private companies), has allowed and motivated them to experiment and start using this type of climate information. In addition, recent research efforts on these priority sectors within climate services, as well as the ability to support long-term decisions (such as strategic plans and corporate investment), also appear to have played a role in the uptake of these typologies of climate information. Whilst there was a degree of bias, given that these sectors were the best represented in the survey, this in itself is an interesting observation. The fact that survey participation is ultimately a self-selection process suggests that these sectors in particular have a greater interest in weather and climate information compared to others. These types of climate information also played the greatest role in *strategic levels of decision-making* in the survey respondents' organisations.

The providers of climate information have also shown to play an important role in the uptake and use of climate information (cf. Bruno Soares and Dessai, 2016). The prominence of NMHS as (both weather and climate) information providers was perhaps expected given the longstanding relationship between these organisations and users, and existing perceptions of these as trustworthy, credible and legitimate producers and/or providers of weather and climate information (cf. Zillman, 2005). Such ongoing relationships with the providers have shown to facilitate the use of climate information in organisational decision-making (Cash et al., 2002; Lemos et al., 2012; Bolson and Broad, 2013; Bruno Soares and Dessai, 2016). From the interviews, it was also noted that the use of other providers of climate information tend to be linked to aspects such as existing protocols between the organisations and the access to additional and/or alternative types of climate information.

An interesting case was highlighted in the discussion of decadal climate predictions, which appeared widespread within the survey sample yet absent from those organisations interviewed due to its currently limited existence in the research realm (Goddard et al., 2012; Mehta et al., 2011). Through the triangulation of research methods in this study it became apparent that this term was poorly understood and misinterpreted in numerous ways (e.g. as synonymous to climate change projections or akin to forecasts for the next decade). In light of this, there is a need to be critical of the extent to which the survey question was accurately understood by the survey participants and whether there may have been some confusion about the meaning of decadal predictions. Indeed, during the interviews there also appeared to be some confusion regarding the difference between decadal climate predictions and climate change projections or between using historical data to predict future changes as opposed to using decadal climate predictions.

Although this somewhat invalidates this aspect of the analysis, it simultaneously highlights an important gap in current understanding and the need for improved communication across scientific-practitioner-policy communities. Moreover, the interviews conducted demonstrated an interest and strong potential for using decadal climate predictions in practice which is aligned with the literature (see e.g. Vera et al., 2010; Cane, 2010). However, the practical use of decadal predictions remains unchartered territory (cf. Dessai and Bruno Soares, 2015) and warrants further research into how this might be developed and translated into usable products.

In the wider context of developing climate services in Europe an understanding of the barriers and enabling factors and conditions that facilitate the uptake and use of climate information is critical. To some extent, many of these factors appear to be shared across sectors such as the format of information, compatibility with in-house systems and the importance of credible sources of information provision. With regards to the latter, there has been a diversification of data provision alongside the increasing commercialisation of NMHS services and the separation of 'basic services' (i.e. provision of free essential information) and more 'specialised services' (i.e. tailored products that respond to specific users' needs and generally provided with a cost attached) (WMO, 2015; Zillman, 2005). This has led to an expansion of the provision of climate information which can enhance and promote innovation within the field of climate services. However, it has also led to a certain level of fragmentation regarding for example, the information available in terms of source, type, format and quality of data. The lack of coordination and mechanisms for bridging this fragmentation can potentially hinder accessibility to data and consistency within sectors. In this context, the existence of a platform that brings together the various actors involved in the development, production and use of climate services in Europe could help bridge the gap between these communities and facilitate and promote a more effective landscape of climate services provision. Such an effort has been forged by the Climate Europe[4] initiative which aims to develop a European framework for the coordination and integration of climate services activities, identify needs and research gaps, as well as enhance and promote the communication between the various involved in climate services. The interviews conducted also pointed out the need for a coordinating body at European level for climate data and information standardisation and provision. The emerging Copernicus Climate Change Service is expected to address (at least part of) this need by establishing itself as a reliable and credible source of free climate information in Europe in the coming years (EC, 2015).

In addition, nuances observed between sectors highlight the diversity of needs and requirements, and importance of not homogenising the 'end-user' as a single group but rather embracing these differences and find new ways of tailoring the climate information provided accordingly. However, this research reveals that there continues to be a gap between user needs and the provision of climate information. In particular, there is a clear interest in the use of decadal climate predictions, yet these remain poorly understood and limited to research-based applications.

In order to increase the use and uptake of climate information in organisational practices, there is a need to address numerous barriers and promote i) better understanding of climate information, including its parameters, limitations and scientific uncertainty; ii) improve coordination and standardisation across fragmented sources of climate information and accessibility; and iii) address current gaps in information provision. It is important however to acknowledge that the use of weather and climate information are usually not applied in isolation as other types of information are also taken into consideration in decision-making processes. Furthermore, wider contextual factors such as institutional factors and cultures towards risk aversion also tend to affect the (potential) users' willingness and/or capability to utilise weather and climate information within their organisations.

More broadly, the uptake of climate information in the context of climate services development in Europe needs to be understood and operationalised as a network of different actors (including intermediary/purveyors organisations) within processes of co-production between the scientific, practitioner and policy communities to better shape the service according to the multitude of users' needs. In turn, this will enhance the uptake and use of climate information in decision-making, help organisations to better prepare, mitigate and adapt to the risk posed by climate variability and change, and more widely support the pursuit of future climate resilient societies in Europe.

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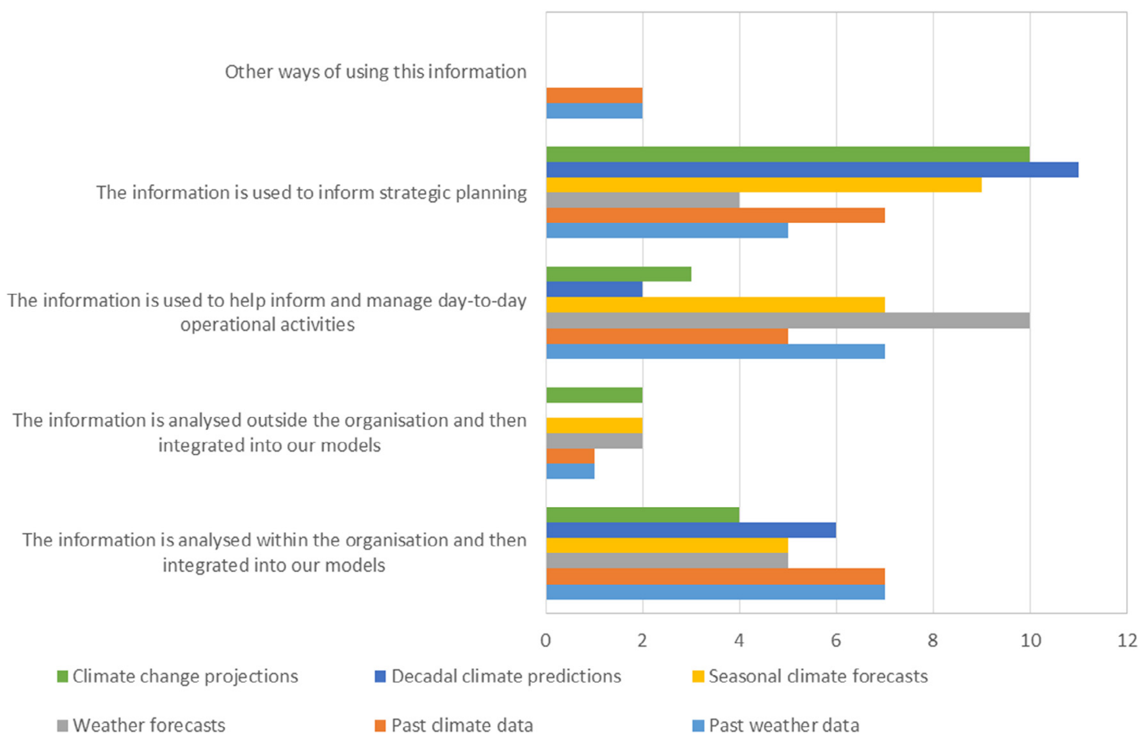
Appendix A.

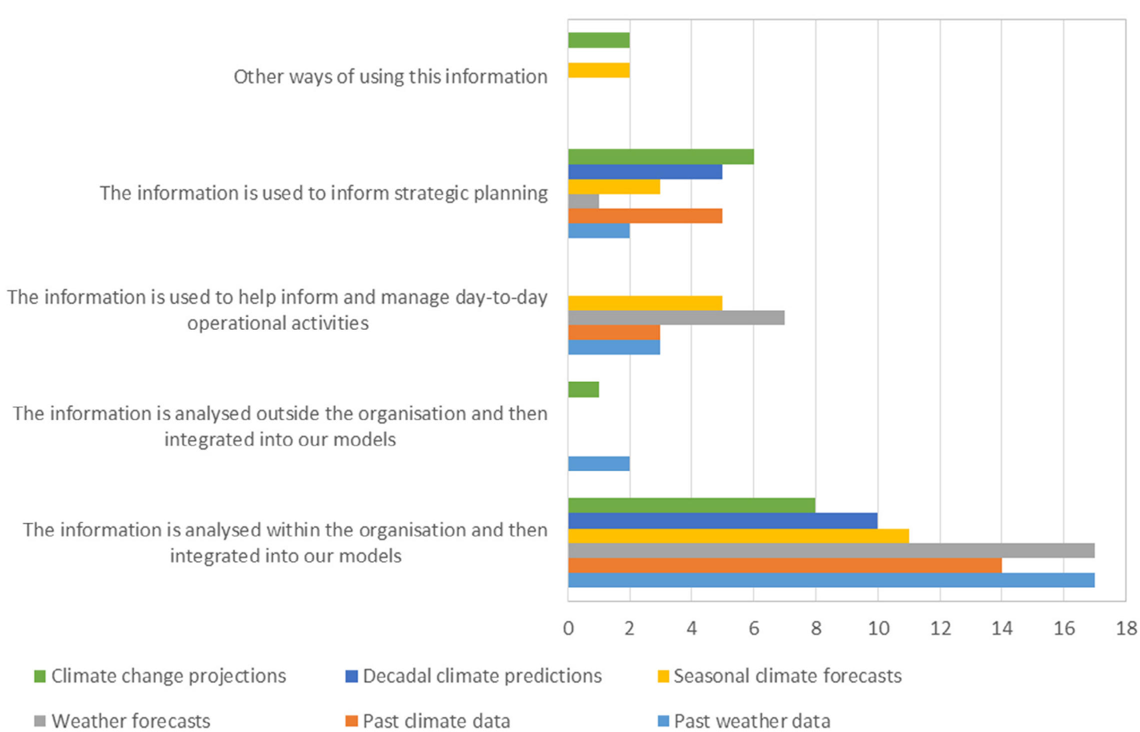
Uses of weather and climate information per economic sector, based on survey results (Note that this was a multi-answer question).

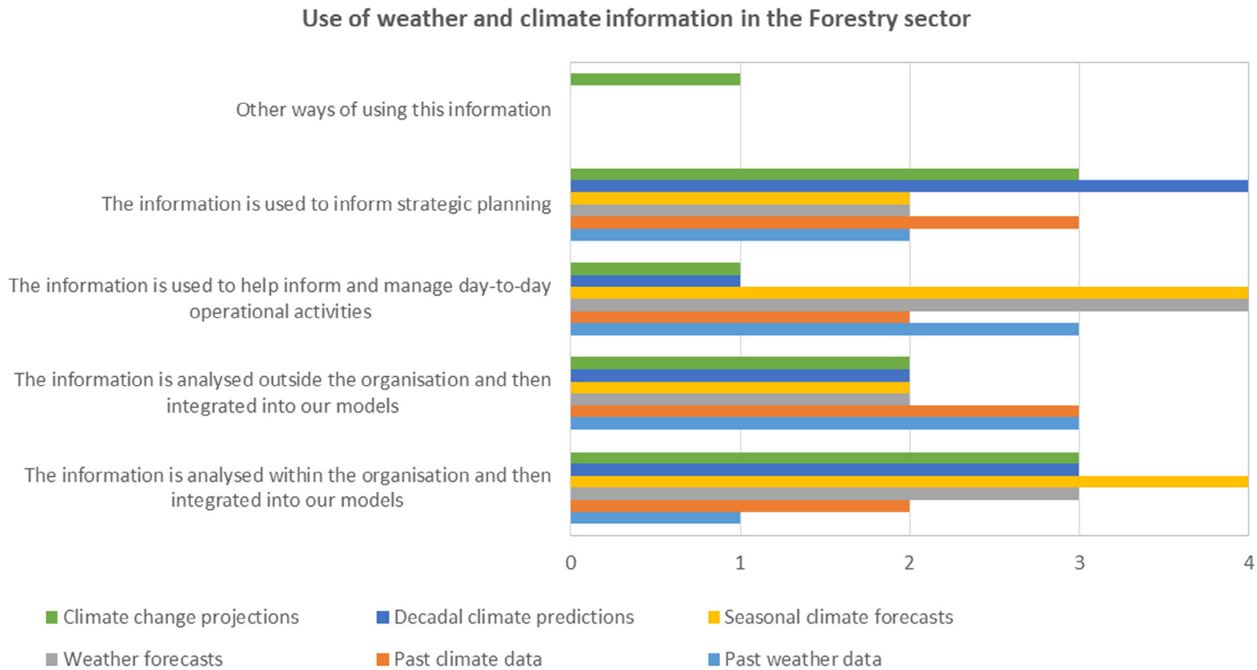
[4] See more information at: http://www.climateurope.eu.

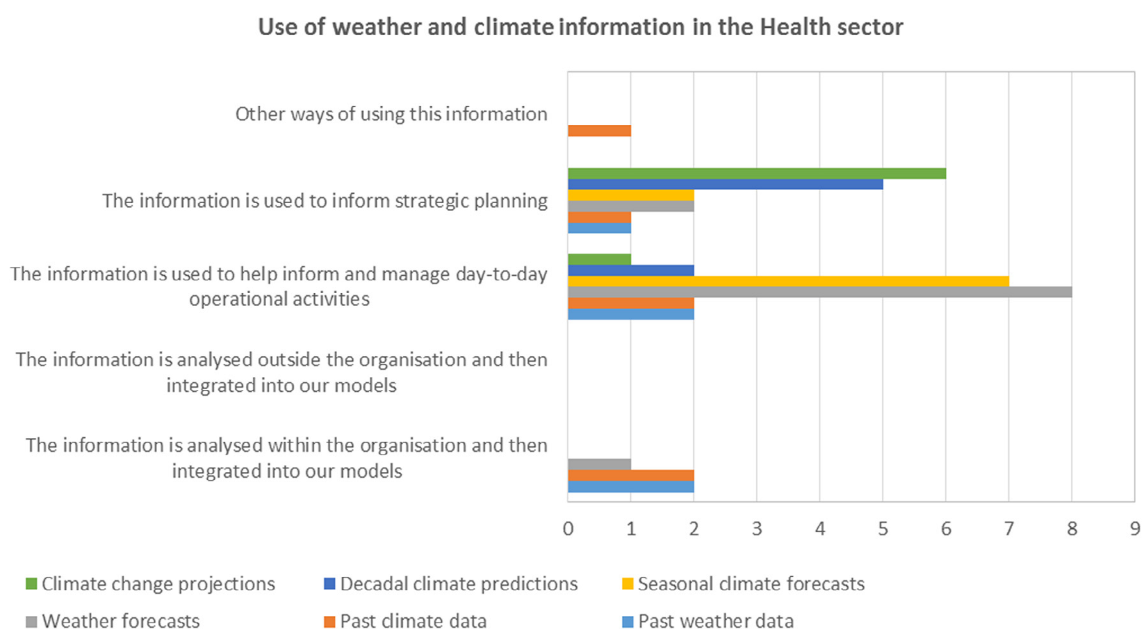
Use of weather and climate information in the Agricultural sector



Use of weather and climate information in the Energy sector




Use of weather and climate information in the Forestry sector
Other ways of using this information
The information is used to inform strategic planning
The information is used to help inform and manage day-to-day operational activities
The information is analysed outside the organisation and then integrated into our models
The information is analysed within the organisation and then integrated into our models
0
1
2
3
4
Climate change projections
Decadal climate predictions
Seasonal climate forecasts
Weather forecasts
Past climate data
Past weather data


Use of weather and climate information in the Health sector
Other ways of using this information
The information is used to inform strategic planning
The information is used to help inform and manage day-to-day operational activities
The information is analysed outside the organisation and then integrated into our models
The information is analysed within the organisation and then integrated into our models
0
1
2
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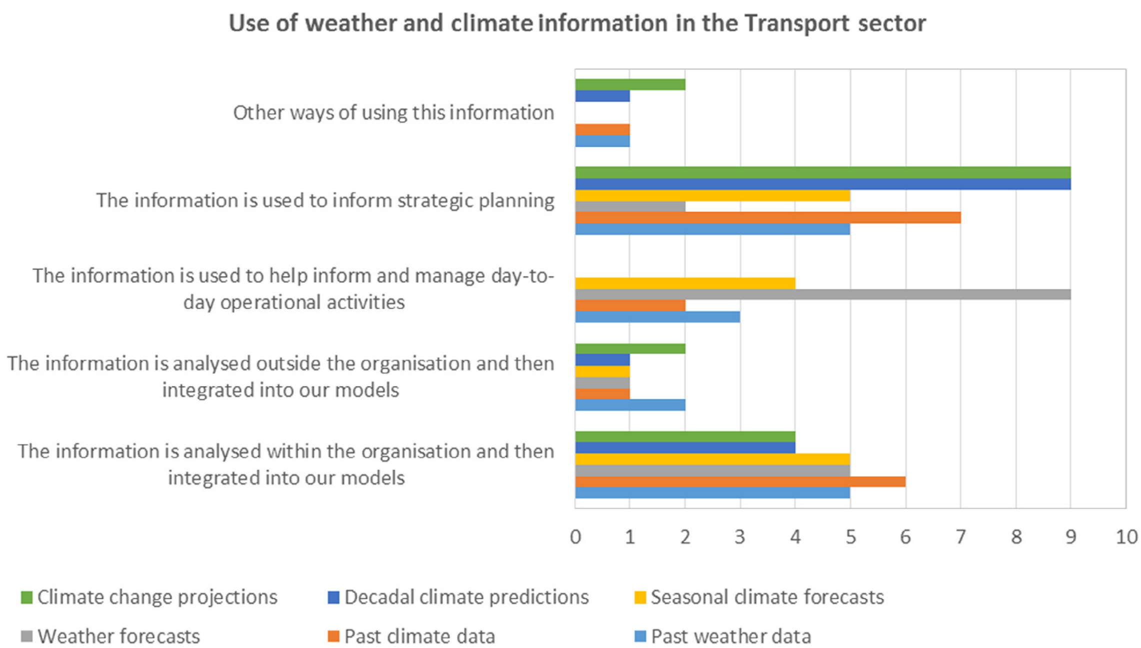
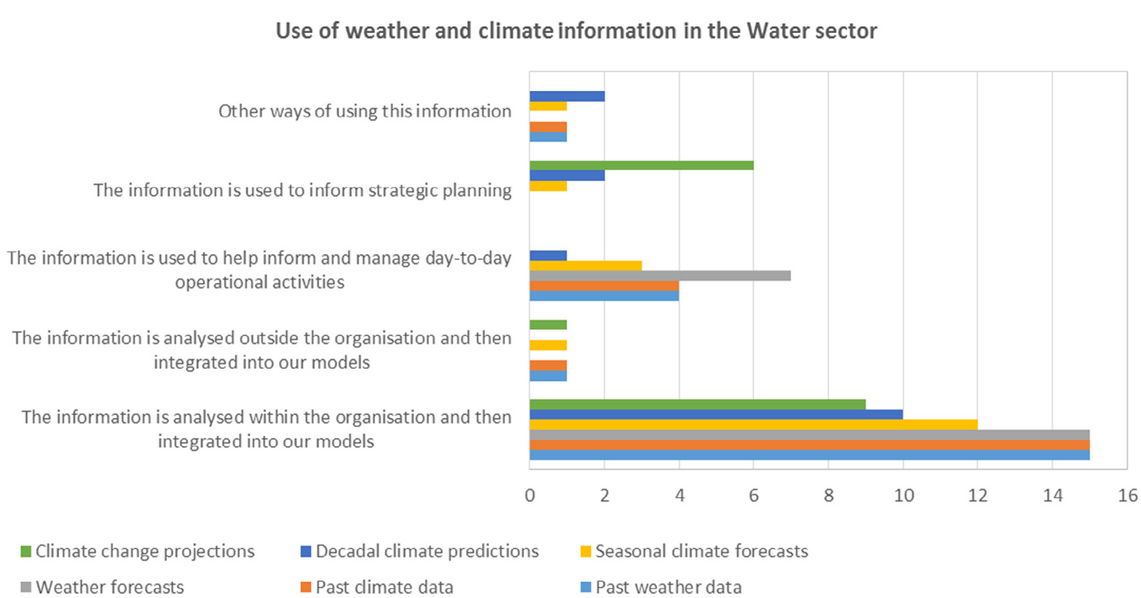
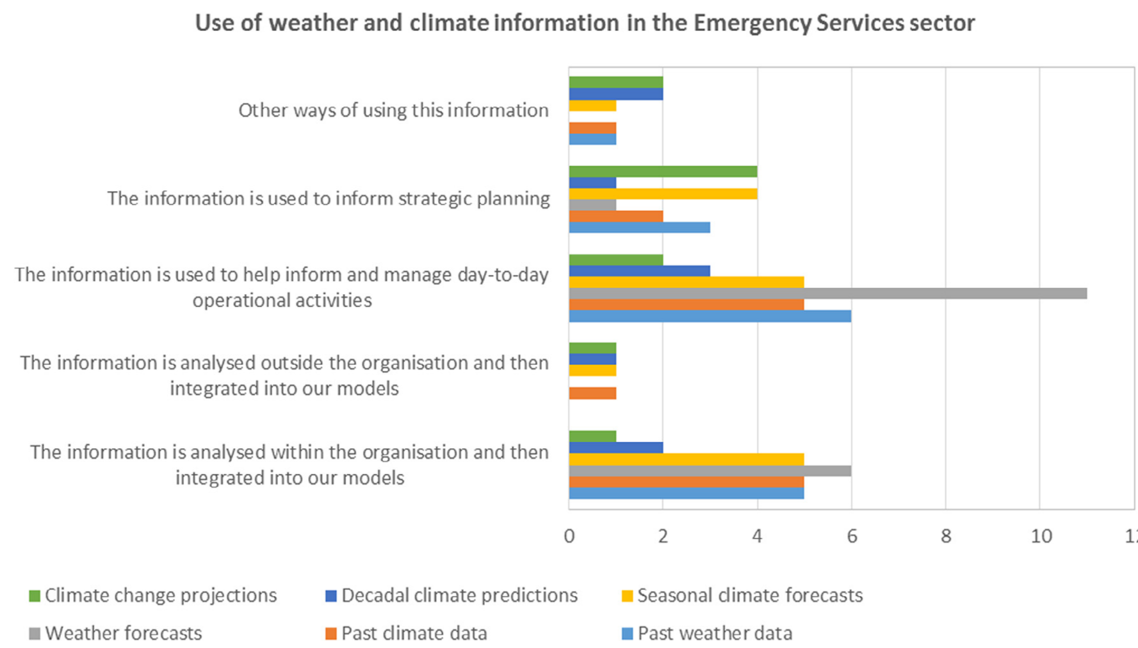
6
7
8
9
Climate change projections
Decadal climate predictions
Seasonal climate forecasts
Weather forecasts
Past climate data
Past weather data


Use of weather and climate information in the Transport sector
Other ways of using this information
The information is used to inform strategic planning
The information is used to help inform and manage day-to-day operational activities
The information is analysed outside the organisation and then integrated into our models
The information is analysed within the organisation and then integrated into our models
0 1 2 3 4 5 6 7 8 9 10
Climate change projections
Decadal climate predictions
Seasonal climate forecasts
Weather forecasts
Past climate data
Past weather data


Use of weather and climate information in the Water sector
Other ways of using this information
The information is used to inform strategic planning
The information is used to help inform and manage day-to-day operational activities
The information is analysed outside the organisation and then integrated into our models
The information is analysed within the organisation and then integrated into our models
0 2 4 6 8 10 12 14 16
Climate change projections
Decadal climate predictions
Seasonal climate forecasts
Weather forecasts
Past climate data
Past weather data



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