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PRIMAVERA

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PRocess-based climate sIMulation: AdVances in high resolution modelling and European climate Risk Assessment

Deliverable D11.6

Report on end-user requirements

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1.0	30/10/17	Erika Palin	Version for submission

PRIMAVERA

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1 Executive summary

A key feature of the PRIMAVERA project is its intention to involve the user community explicitly in the development, dissemination and use of the climate risk information that the project will provide. As part of this task, a series of user engagement and dissemination activities has been planned (D11.1) and is now in progress.

An assessment of user needs for climate information has been made through an online survey and a series of one-to-one interviews with key stakeholders. The focus has been on the key sectors of energy, transport, and insurance, but some progress has also been made in other sectors (water, health, and agriculture).

The topics probed by the survey and interviews included:

- Existing use of weather and climate information, including sources, and type of information used
- Existing knowledge and experience of weather/climate impacts on sectors/businesses
- Levels of existing knowledge of, and engagement with, climate change as a topic
- Desirable data characteristics for data coming from PRIMAVERA (format, temporal coverage, spatial and temporal resolution)
- Preferences for other types of PRIMAVERA product, besides data (visualisations, guidance, training)
- The outcomes of the survey and interview analysis are presented by sector, and some comparison across sectors is also made. Each user is different, with a different background, a different level of weather/climate "literacy", a different job role and purpose, and therefore a different set of requirements for what PRIMAVERA might usefully provide to them. However, some general themes can be drawn out, whether these are particular to a sector or to some other aspect of the users involved.

An initial assessment of the feasibility of delivering to particular user needs is presented. While not all needs and preferences can be addressed within the project (or indeed by the prevailing science in general), there are clear areas where PRIMAVERA should be able to add value for the user community.

Following these activities, next steps are to continue the engagement activities in WP11, and to continue to work closely with WP10 to explore what can actually be provided within the scope of PRIMAVERA that will have a positive impact on users.

2 Project objectives

With this deliverable, the project has contributed to the achievement of the following objectives (DOA, Part B Section 1.1) WP numbers are in brackets:

No.	Objective	Yes	No
A	To develop a new generation of global high-resolution climate models. *(3, 4, 6)*		✓
B	To develop new strategies and tools for evaluating global high-resolution climate models at a process level, and for quantifying the uncertainties in the predictions of regional climate. *(1, 2, 5, 9, 10)*		✓
C	To provide new high-resolution protocols and flagship simulations for the World Climate Research Programme (WCRP)'s Coupled Model Intercomparison Project (CMIP6) project, to inform the Intergovernmental Panel on Climate Change (IPCC) assessments and in support of emerging Climate Services. *(4, 6, 9)*		✓
D	To explore the scientific and technological frontiers of capability in global climate modelling to provide guidance for the development of future generations of prediction systems, global climate and Earth System models (informing post-CMIP6 and beyond). *(3, 4)*		✓
E	To advance understanding of past and future, natural and anthropogenic, drivers of variability and changes in European climate, including high impact events, by exploiting new capabilities in high-resolution global climate modelling. *(1, 2, 5)*		✓
F	To produce new, more robust and trustworthy projections of European climate for the next few decades based on improved global models and advances in process understanding. *(2, 3, 5, 6, 10)*		✓
G	To engage with targeted end-user groups in key European economic sectors to strengthen their competitiveness, growth, resilience and ability by exploiting new scientific progress. *(10, 11)*	✓	
H	To establish cooperation between science and policy actions at European and international level, to support the development of effective climate change policies, optimize public decision making and increase capability to manage climate risks. *(5, 8, 10)*	✓	

Please note that this deliverable also fulfils project milestone **MS27**, "End-user requirements for climate information and their preferred delivery and visualisation methods documented".

3 Detailed report

3.1 Engagement methods used to complete this report

Climate services strongly depend on successful engagement between the users and the providers of these services. It is argued however that this interaction is at the same time the least-developed aspect of climate services (WMO, 2014; Hewitt et al., 2017). PRIMAVERA applies a participatory design approach to enhance this interface between the project and the potential users of PRIMAVERA products. The stakeholders were first involved in a short online survey about user needs for weather and climate information. The survey was followed with more in-depth one-to-one interviews. Stakeholders[1] from the key PRIMAVERA sectors – energy, transport and insurance, were approached. However, we also involved stakeholders from water, agriculture and health, to widen our understanding of various user needs. As many channels and stakeholder lists were used, it was not straightforward to track how many organisations were originally approached, but ~150 is a reasonable estimate.

3.1.1 Survey analysis

We conducted an online survey within the PRIMAVERA project as a first step towards understanding user needs for weather and climate information and establishing contact with users from different sectors of interest for the project. The survey was aimed at a broader audience and used the questions and the language applicable for different user profiles. Participants were however asked if they would like to be involved in the more detailed follow up interviews. Responses were collected over a period of approximately three months (from 7 February to 9 May 2017). The survey was distributed to the PRIMAVERA WP10 and WP11 partners' stakeholders and through the Climate Services Partnership newsletter; and promoted in the PIANC conference poster and via the @MetOffice_Sci and @climateurope Twitter feeds. Altogether 83 complete responses were received from the participants from 12 different EU countries (Figure 1), while one participant was from the US.

[1] The terms user and stakeholder are used interchangeably in this report. Stakeholders or users include all those that can be interested in and/or can benefit from PRIMAVERA outputs.

Figure 1: Survey participants' (organization) location

3.1.1.1 *General survey analysis*

This section presents results from a selection of questions asked in the survey.

3.1.1.1.1 Sector of work

The survey participants worked in different sectors (Figure 2). Participants were able to select multiple sectors and of the eight options offered (transport, energy, insurance, health, agriculture, water resources, natural environment, urban), 49 participants selected only one sector, ten selected two sectors, five selected three sectors, and the remaining nine participants selected four or more. In addition, participants were able to specify other sectors; amongst those specified, five participants stated that they worked in research, four in meteorology and climatology, three in climate change adaptation and mitigation, and two in disaster risk reduction.

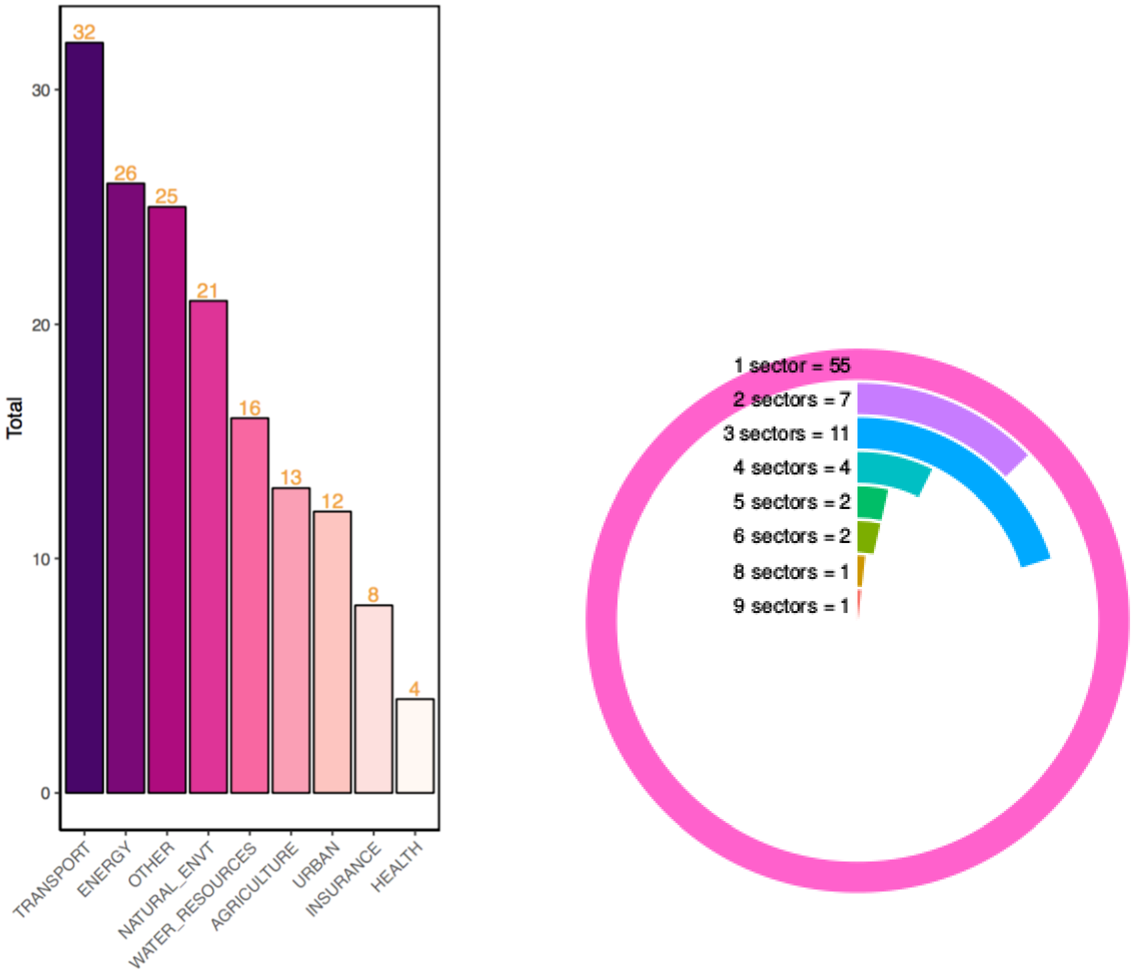

Figure 2: Survey participants' main sector(s) of work (left), number of main sectors of work selected by participants (right)

3.1.1.1.2 Role type

The participants were mainly researchers (Figure 3), from sectoral organisations and academia. However, we received answers from a total of 26 participants from operations and planning background, focusing mostly on service delivery and strategic-planning. There were also 12 decision makers or participants holding high-level managerial roles. The remaining 12 held various other positions such as coordinator of national protection plans, senior consultants, middle managers, and technical advisors to name a few.

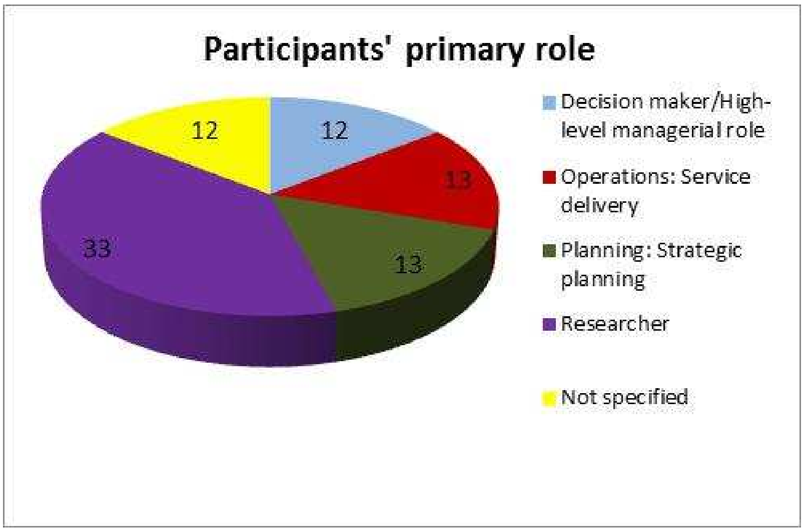

Figure 3: Survey participants' primary role in their organisations

3.1.1.1.3 Importance / influence of weather / climate change on participants' work

We asked participants how important weather and/or climate change was to their personal work and for the professional decisions they made. We also asked them if at present, climate or weather hazards had an influence on the work of their organisation. For 55% of the participants, weather and/or climate (climate change) are very important for their personal work or for the professional decisions they make and for 42% they are quite important. Figure 4 summarizes the answer to these questions based on the participants' primary role. It can be seen that only one researcher and one strategic planner stated that climate change was not important for their work.

Participants were asked to rate a set of weather / climate-related hazards in terms of either the impact of those hazards on their organisation, or the degree of research interest in those hazards, using the same scale.

When it comes to the hazards that have influence on the work of the involved organisations, rainfall and rainfall-related flooding, as well as high winds were hazards with largest effect (Figure 5). Altogether very few participants said that their organisation's activities were not affected by climate hazards. As Figure 4 presents, most of the participants, regardless of their primary role, were either already directly affected by climate hazard or believed they might be affected in the future.

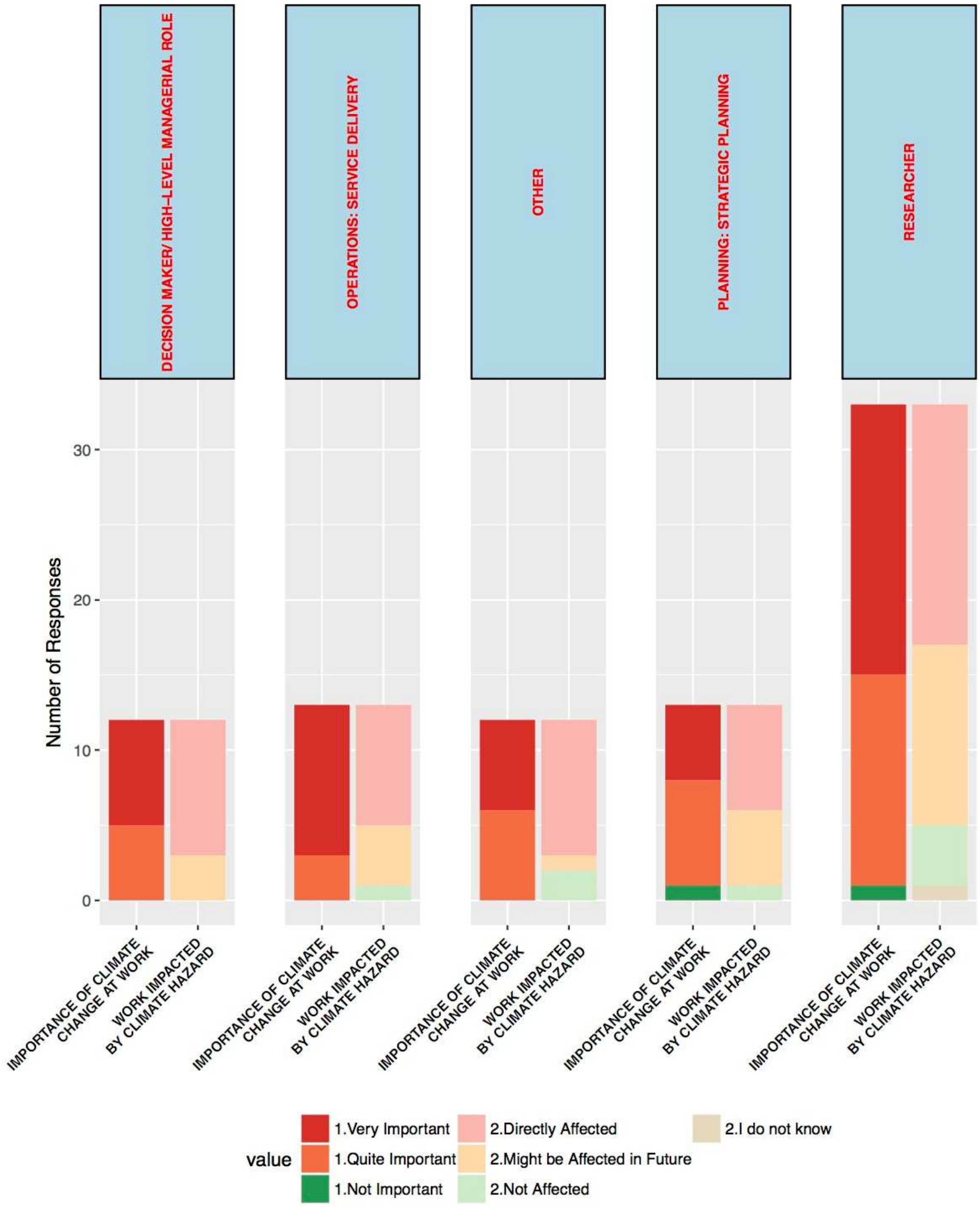

Figure 4: Importance of climate change and impact of hazards for different user profiles in the survey

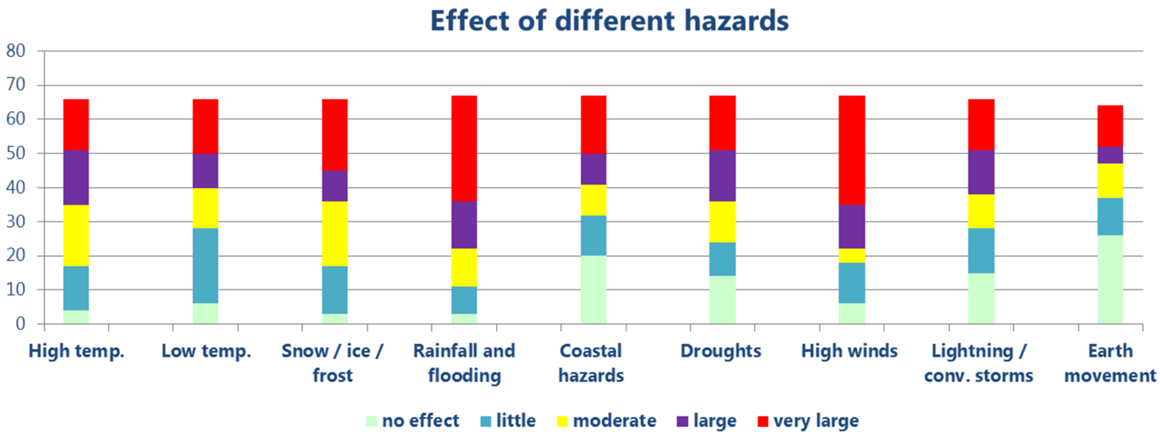

Figure 5: Effects of / research interest in different hazards for the survey participants' work

3.1.1.1.4 Use of, and source of, weather and climate data/information

Most of the participants access data from National or European hydro-meteorological or environmental agencies, but they also use information from research institutes, project websites and information provided by the private sector (Figure 6).

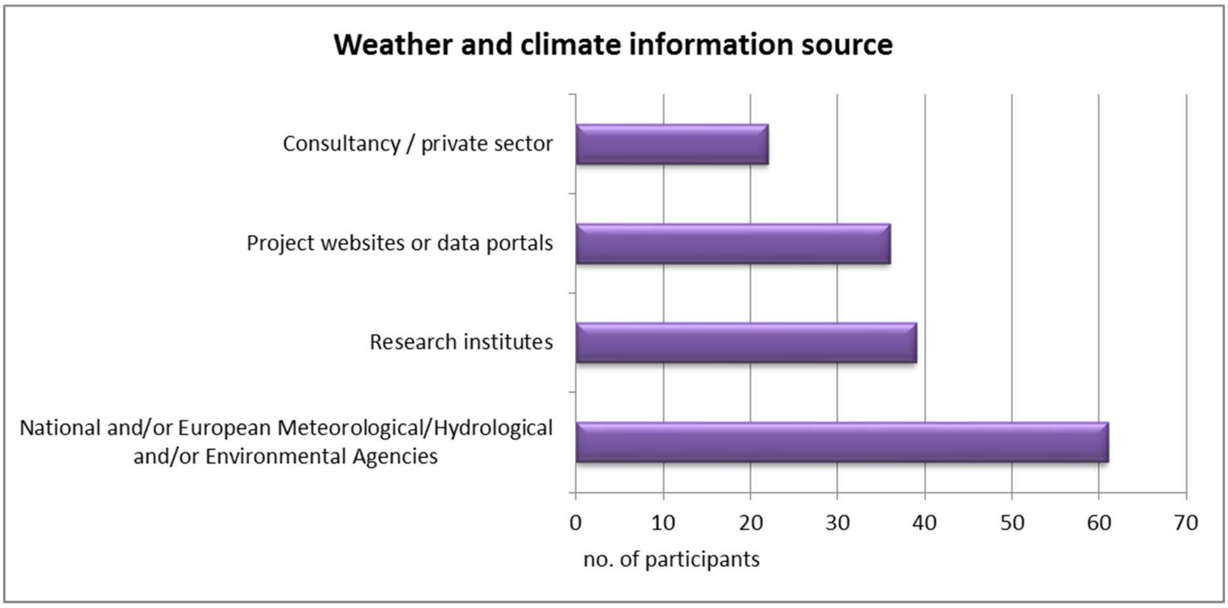

Figure 6: Survey participants' weather and climate information source

Figure 7 presents where participants with different profiles access data from and what they use it for. Besides high-level decision makers, not many other participants got their climate information from consultancies and private sectors. Some also used other sources such as air traffic, air transport or air quality monitoring network management companies, while others generated their own climate/weather information. The participants used these types of weather/climate information mostly because it improved the quality of their decision-making and secondly because this information was available to them. Participants who used the climate information because of legislative or regulatory duty were very few, and mostly from strategic planning background. Other reasons for using weather and climate information were for inclusion in work-specific highly customized tasks or models such as energy simulation of buildings, specific air quality models, for safe ship movements simulations, as thresholds for national control instructions, etc.

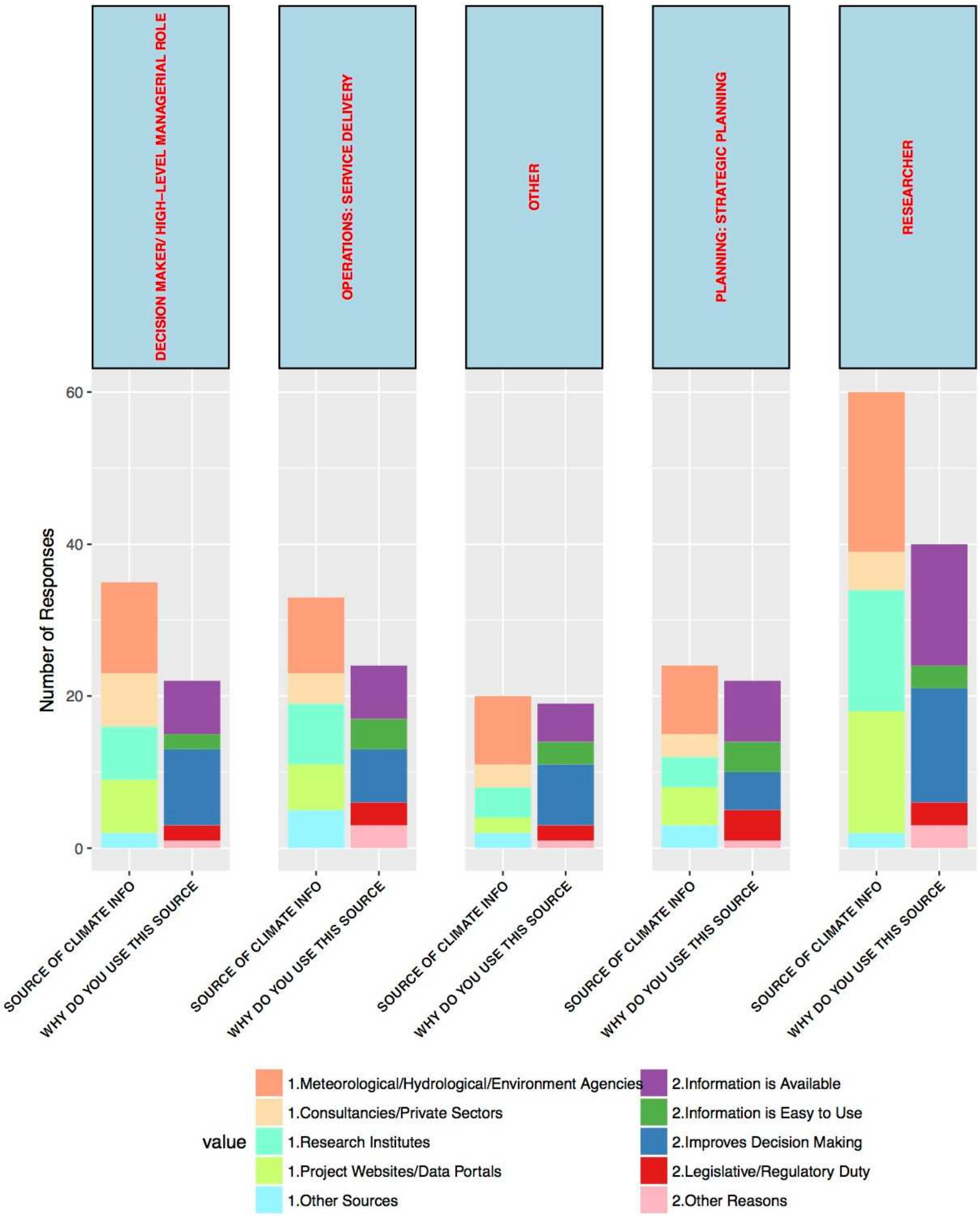

Figure 7: Source of climate information and motivation for their use for different user profiles in the survey

Weather and climate information is mainly used for research activities, immediate or short term planning and operational activities, to raise awareness outside of the organisation, but also for other purposes (Figure 8).

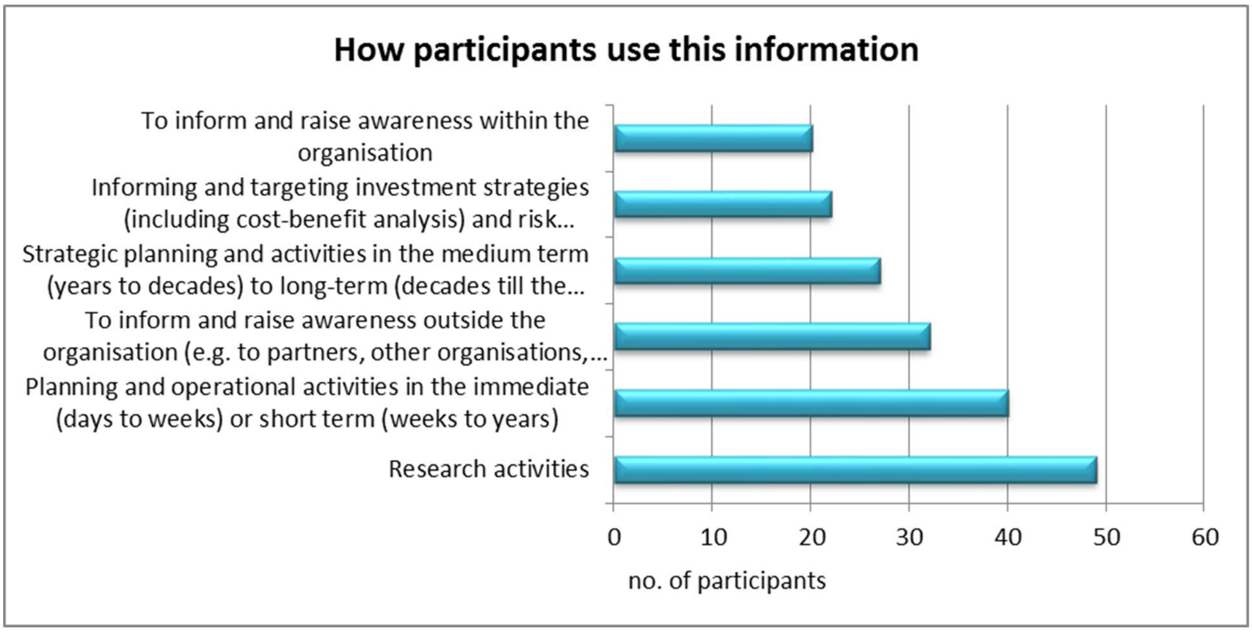

Figure 8: Purpose of survey participants' use of weather and climate information

3.1.1.1.5 Lack of use of available information, and reasons for this

Table 1 presents answers provided to the question about the types of weather or climate information the participants think could help them fulfil their role, but that they do not currently use. The survey provided comment fields under four categories: information for specific variables or hazards, information on the right time scale, information on the right spatial scale, or any other information.

The main reason for not currently using such information was technical barriers, but the participants also selected knowledge and cost related barriers (Figure 9). However, in the comments field, the participants further specified that sometimes it is a combination of these aspects, or that users are sceptical about the practical usefulness of this information. Besides, one participant pointed out the language barrier, which limited awareness in their organisation about the existence of some information.

Table 1: Types of weather/climate information that survey participants do not currently use, but that could help them to fulfil their current role (Note: responses are quoted verbatim from the survey)

Weather/climate information for specific variables/hazards	Weather/climate information on the right timescale	Weather/climate information on the right spatial scale	Other
• Anticipated rain, snow, winds, humidity... • Extreme wind events and storm events with lighting component • Future wind climate • Hail data/maps • High spatial density observational wind and radiation network • Improved jet stream variability prediction • Reliable hourly solar radiation data • Sea level rise; Extreme events (storm, heavy rainfall etc.) • Solar Radiation • Solid precipitation scenarios (2018-2030) • Wind, storm, blizzard	• Annual/decadal forecasts • Climate information on the sub-daily timescale (plausible realisations) and spatially coherent • Decadal and Seasonal timescales • Hourly time scale • Long-term records • Future climate increasingly important • Improved frequency of metrological information (in particular wind), preferably hourly rather than the current 6 hourly global weather forecasts • Large scale, climatological scale (20-30 years) as well as seasonal scale • Short to mid-term seasonal forecast	• At local level • High resolution terrain information • <1 km • <2 km • 10km • Ideally microscale (3x3km) but anything close to that would be really welcome • Both for climate and weather model output the resolution is nearly always an issue. Although improving, there is always a scale mismatch • City scale • Consistent gridded data for multiple variables (temp, precipitation, wind) • Details on specific regional level (for use in geographical systems), valid weather projections (e.g. storms, rain) for risk assessment and HotSpot analysis • Finest possible spatial scale • Hourly climate data at urban neighbourhood scale • Improved resolution of atmospheric metrological information, preferably at 1,000 ft resolution from ground to 50,000 ft. • Regional and local scale for climate scenarios • Temperature and precipitation scenarios for complex terrain	• Climate Modelling • High resolution observation datasets • Quantifying potential impacts • impact data • Information that is translated into something the public can understand. At a regional scale what would the projections actually look/feel like through a year. • The problem is usually too much. Hundreds of models and scenarios and for a non-climatologist it is difficult to tell how to make a proper selection or how to combine the many options into a workable whole. • Trade off between spatial and temporal resolutions • It would be nice to have international standards on data format, so that researchers can easily access to data of any country

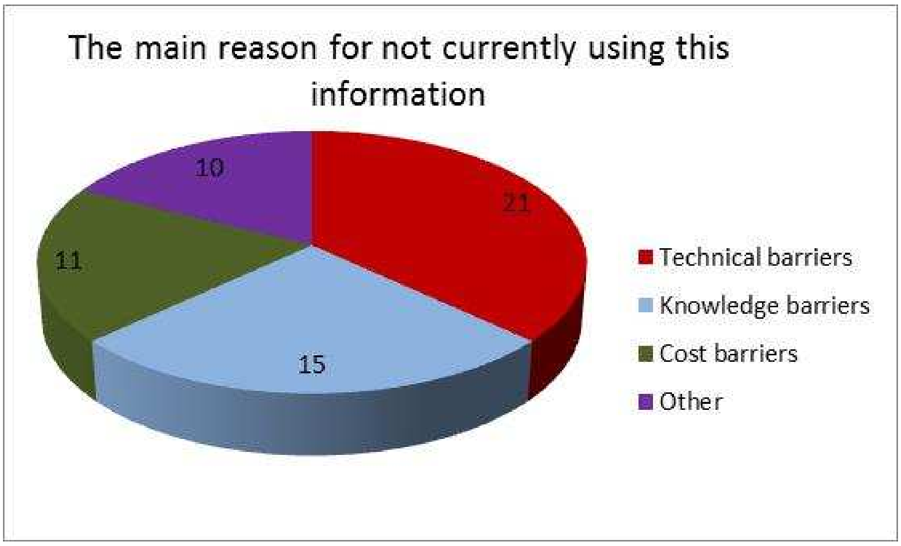

Figure 9: Main barriers for not currently using weather and climate information mentioned in the previous question

Some user requirement themes emerge from Table 1. The comments therein regarding hazards/variables include some which could be addressed by PRIMAVERA and some which probably cannot. The question about timescales was interpreted by many as lead time (time between now and the validity period of the prediction/projection) rather than our intended interpretation (temporal resolution of the information). Several users highlighted the seasonal to decadal timescale as of interest to them. There is scope for providing useful outputs to address these needs, e.g. from WP5.

There is still some disparity between the spatial data resolution desired by users and that which can be provided by global climate model simulations (see also sector-by-sector interview analysis below).

Finally, there were insights into additional user requirements for the information that they would like to receive in the final column of Table 1, with users wanting understandable material, guidance on how to select appropriately from the wealth of available information, and information about impacts specifically.

3.1.1.1.6 Anticipated usefulness of high-resolution PRIMAVERA data/information

Although the primary goal of PRIMAVERA is to explore and exploit the benefits of increased resolution on the modelling of the 'global' climate, this increased resolution also enables the production of surface impact data at much higher resolutions (~25-60km) than is typically available from standard climate models (~100km+). Users were therefore queried about the anticipated benefits that access to higher resolution surface weather data will bring to their organizations.

Responses indicated that information on the finer spatial scales produced in PRIMAVERA would be useful for most of the involved organisations. Out of the 63 participants that answered this question (76% of all respondents), almost 30% were not sure whether this resolution would be useful, however (Figure 10).

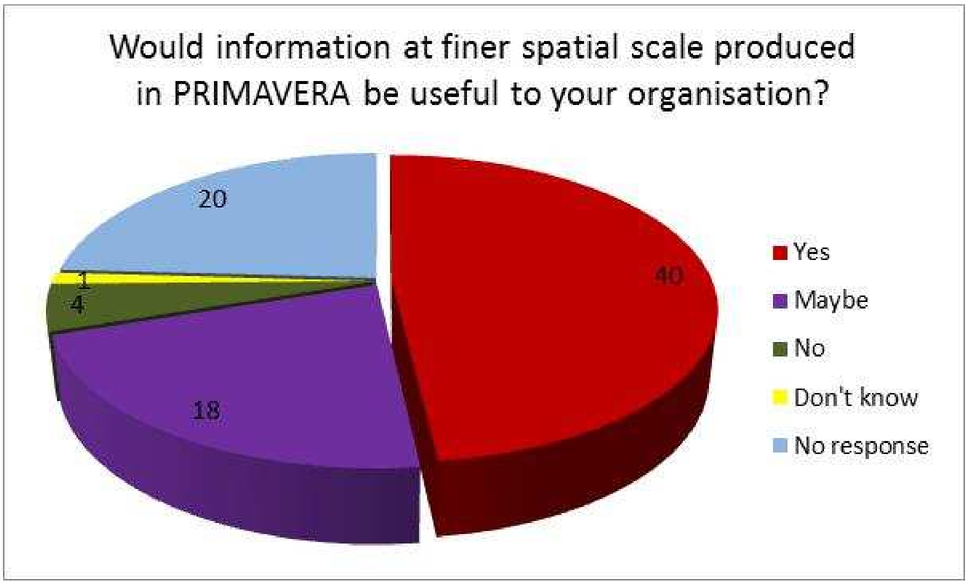

Figure 10: Usefulness of information at finer spatial resolution produced in PRIMAVERA

It is fair to say that not all users would necessarily have grasped the subtlety of this question. Some users would have understood it in terms of its "basic" meaning: namely, having access to more localised data outputs (e.g. for those interested in a point location such as a power plant or transport hub, being able to find a grid box closer to their desired "target").

However, PRIMAVERA is not simply about increasing resolution, but rather about evaluating whether higher resolution *adds value* in terms of the representation in the PRIMAVERA-era models of physical processes with user relevance. More advanced users might have understood this more subtle aspect of the question. Either way, the question gives cause for optimism about how the PRIMAVERA outputs could ultimately be received by the majority of users.

Figure 11 presents answers to the question about the importance of climate change and usefulness of high resolution based on the participants' primary role. While most of the participants said that climate information at higher resolution would be helpful for their work and their organization, quite a few were unsure if it would add value to their work. Only four participants, one decision-maker, one planner and two without specified roles said that high resolution climate information would not be useful to them and interestingly, some participants (mostly researchers) did not respond to this question. In the more profound interaction with users, that followed up the survey with interviews (see the following sections of this report), we confirmed that most of the participants would appreciate higher data resolution. Nonetheless, a few interviewees expressed their satisfaction with the data resolution – either spatial or temporal – that was currently available to them.

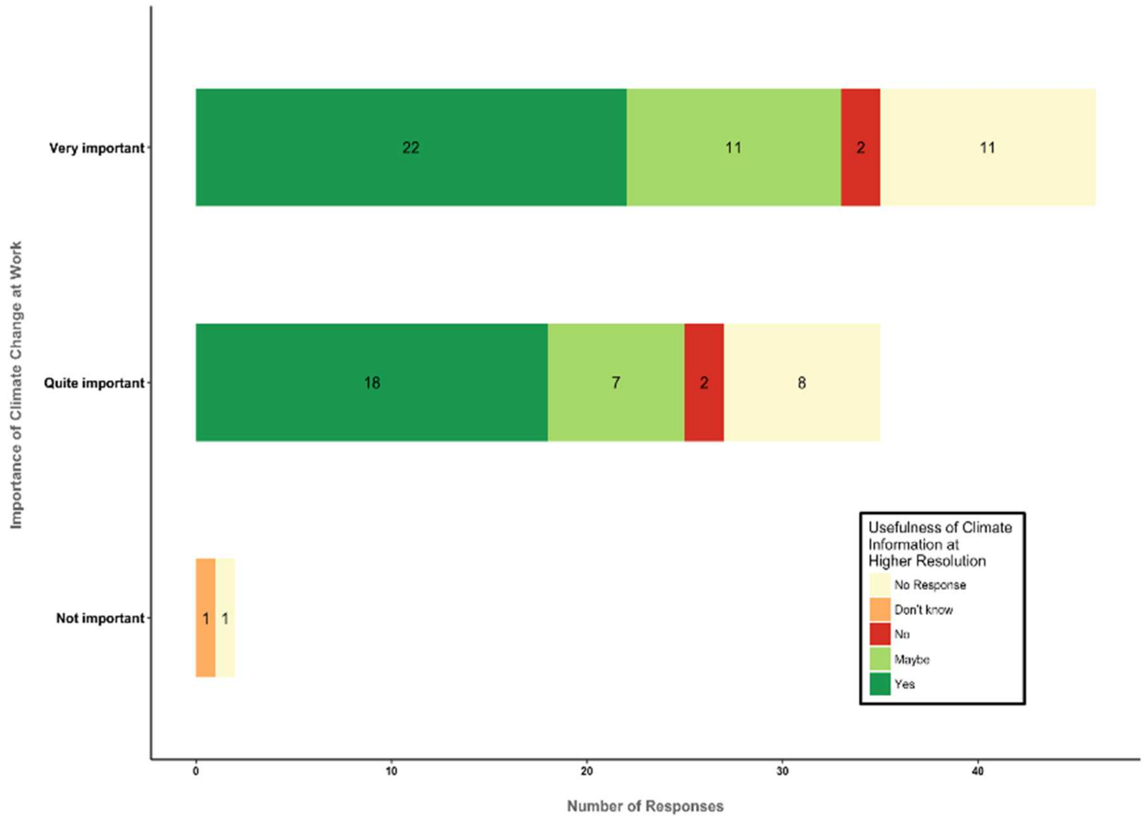

Figure 11: The importance of climate change and usefulness of higher resolution for different user profiles in the survey

Besides the four specified types of information products (guidance & descriptive, data & technical, visualised, training), participants stated that they would also like to receive:

- Description of uncertainty
- Easy access and download of data (e.g. opendap), remote computing facilities
- Observational data and community models[2].

In the final comments field, participants provided a few more recommendations which they felt would be useful in the context of this survey. This includes interest in descriptive information such as "extremes of 19xx become normal by 20xx" and in information about uncertainties related to the climate projections and how to interpret them. One participant suggested that translating what the projections might mean for the average person would help them conceptualise the potential change and so encourage mitigation or enable more realistic resilience and adaptation planning. Finally, one participant expressed concern that "the whole PRIMAVERA project is

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[2] "Community models" are those which are developed by a community of interested parties, sometimes with expertise in different areas, for mutual benefit. An example is the Joint UK Land Environment Simulator (JULES, http://jules.jchmr.org/)

driven by what the scientists want to do (run ever bigger models) and not at all by what society needs (which is better access to observational data).” We however anticipate that the current and planned user-oriented activities will assist the project to address societal needs.

From the closing questions, 70% of the participants would like to receive occasional information and updates about the PRIMAVERA project. 15% would not like us to share this information with them and the same percentage did not answer this question. Just over half of the survey participants (52%) were willing to participate in a PRIMAVERA interview, while 30% were not, and 18% skipped this question.

3.1.1.2 *Climate hazards ratings*

Figure 12 is a heatmap that shows the extent of the effect of various climate hazards on the participants’ work or that of their organisations (or, if there is no direct effect, the extent to which the hazards are of research interest). It shows that around three-quarters of the participants perceive either a large or very large impact from rainfall and rainfall related floods (“Rain_flood” in Figure 12). Wind is another major climate hazard with around 70% of participants being affected by high winds to a large or very large extent. Other hazards such as high or low (extreme) temperatures, snow, ice and frost, coastal hazard, droughts and lightning storms are also concerning to the participants as over 40% said they were affected by these hazard either largely or very largely. Earth movement is the climate hazard of least concern across the whole group, with around 70% of participants saying it had little or no effect. However, one-fifth of participants still rated this hazard as having a large or very large effect.

Figure 12: Hazards that affect the work of the survey participants and their effect

In Figure 13 and Figure 14, we provide a further breakdown of the extent of these climate hazards divided into 5 specific sectors: energy, transport, insurance, agriculture, and water resource management. This figure helps us identify if some of these hazards are more sector-specific. For example, it can be noticed that coastal hazards clearly affect insurance sector (88%) at a higher extent than the rest of the sectors. Similarly, 70% of the participants in agriculture agreed that high temperatures affect them largely or very largely. Similarly, 100% of the participants agreed that droughts affect them largely or to very large extent. Thus, while important also to other sectors, high temperatures and droughts are climate hazards of major concern for the agricultural sector.

Rainfall and rainfall related flooding is the most concerning climate hazard among the participants. Indeed it has major effects on all the sectors, except energy where only half of the participants said they were largely or very largely affected. High winds, on the other hand, are more concerning to the energy, transport and insurance sector than to agriculture and water resource management. Finally, earth movements as seen before, are less concerning to all the sectors with an exception of the transport sector, where for 39% of the participants earth movements largely or very largely affect the work of their organisation or the sector.

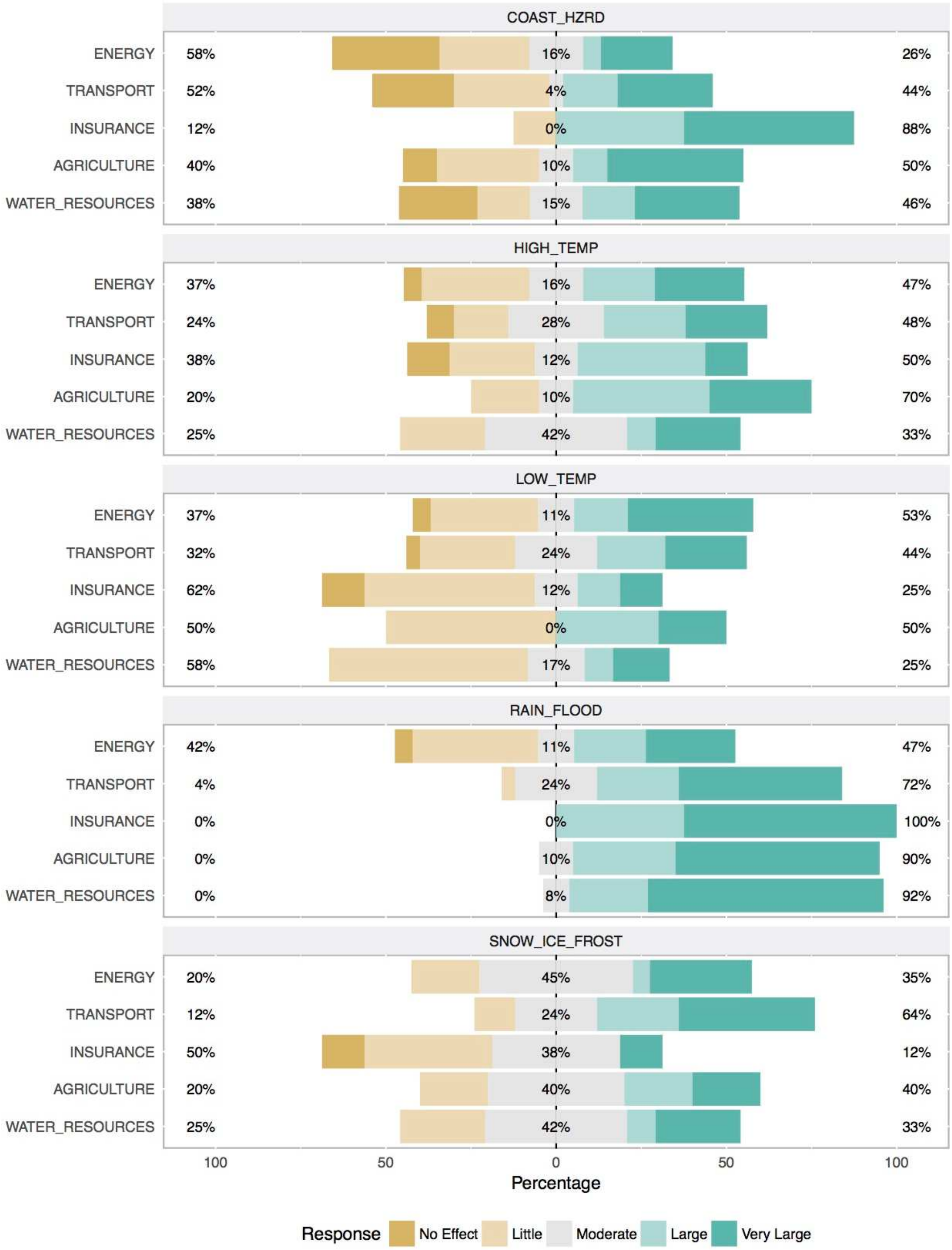

Figure 13: Effects of different climate hazards on the five analysed sectors in the survey

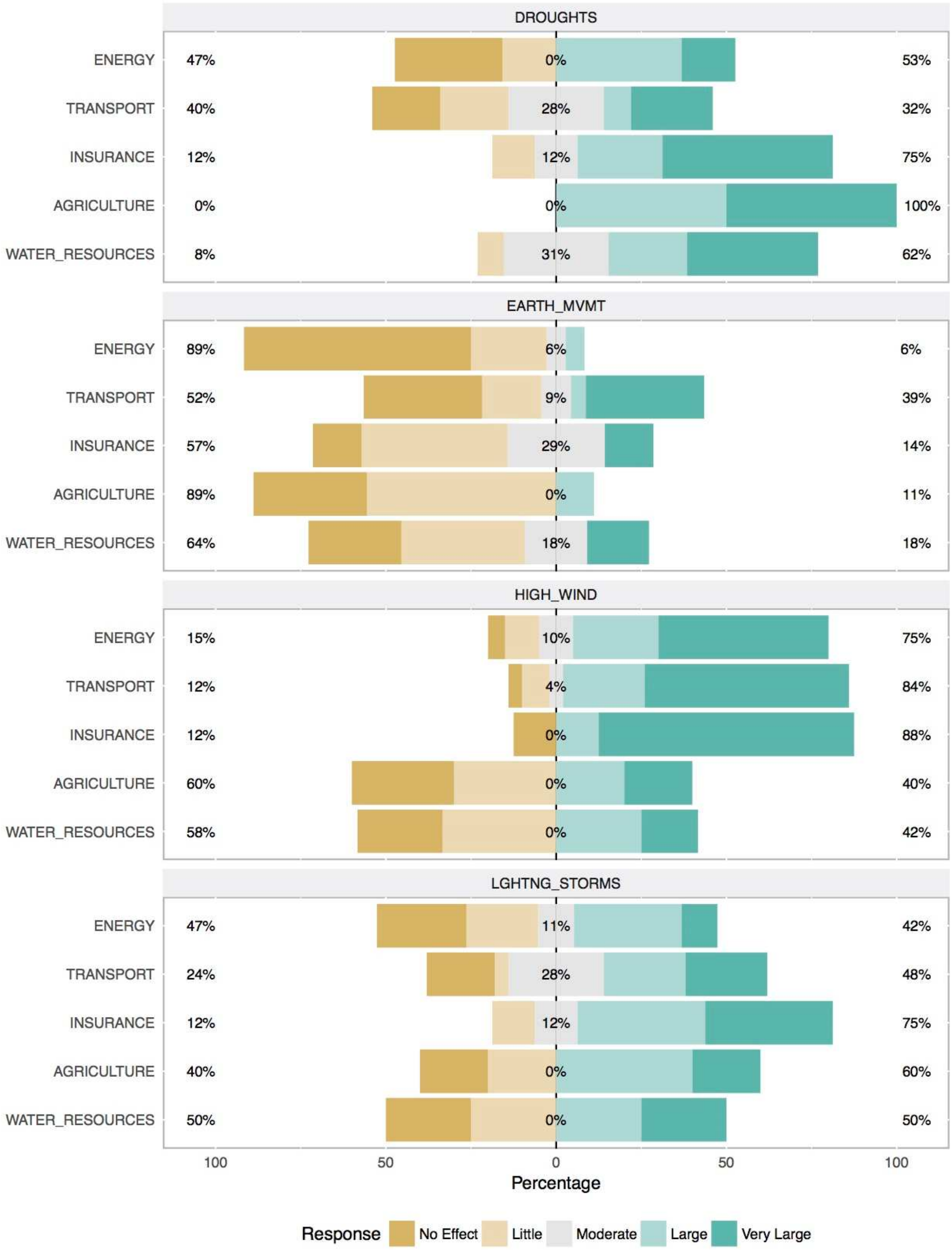

Figure 14: Effects of different hazards on the five analysed sectors in the survey (cont.)

3.1.2 Interview analysis: overview

All participants who stated that they were willing to be interviewed were invited, though some did not respond to the initial approach email, or to a follow-up message. A few additional approaches were made to people who did not participate in the survey. We contacted stakeholders from the three key PRIMAVERA sectors: energy, transport and insurance, as well as from the three additional sectors: water, agriculture and health. A total of 47 interviews were conducted during the period May-September 2017.

There was some geographic bias in the interviews; coverage in the survey was generally better, but in inviting interview participants, we were inevitably limited by those who had consented to be interviewed.

From the survey analysis, three sets of semi-structured interview questions (Appendices A-C) (energy: 15, insurance: 8, transport: 12, water: 7, agriculture: 3, health: 2) were developed, aimed at academics, consultants, and users respectively. While the questions in each version probed the same topics, the wording was subtly different to reflect the differing nature of these roles. Academics can speak on behalf of their own specific research interests, and/or those of their collaborators, in academia and in industry. Similarly, consultants can speak on behalf of their own organisations, and/or their client organisations. Users would normally be speaking on behalf of their own organisation specifically and perhaps even their specific role – though there were some users who spoke on behalf of a sector, e.g. those representing “umbrella” organisations.

A sector-by-sector analysis of the interviews conducted is presented below (Sections 3.1.3–3.1.8), followed by a cross-sectoral analysis (Section 3.2).

3.1.3 Interview analysis: energy

3.1.3.1 *Introduction*

3.1.3.1.1 Participants characterisation

We interviewed 15 participants from the energy sector. The interviews are divided into three thematic groups of five participants. We conducted the analysis for each group, which is followed by a discussion about the common characteristics and main differences between these three groups:

- Group I – Management, research and consulting: Electricity system/power sector
- Group II – Consulting: Renewable energy
- Group III – Research and Development

GROUP I: Electricity system/power sector

This group is composed of five interviewees whose work is focused on the safety of the electricity system. This includes both the physical safety, such as the security of the grid and the energy market safety. Some of the answers, e.g. related to which hazards affect their work, are reflecting the need of their customers, while others are from the companies' perspective. Their customers span from private companies, to utility companies, regulators and governments. Participants from this group did not take part in the PRIMAVERA survey. The stakeholders in this group have the following roles:

- Risk and resilience analyst
- Expert on extreme weather and safety aspects
- Energy analyst focused on the flexibility required from the electricity system
- Electricity market analyst
- Researcher in energy systems

Having as their focus the electrical system as a whole, the participants in this group were concerned with both the conventional energy production – e.g. nuclear power safety, and the renewable energy production – e.g. the flexibility the system needs for supporting intermittent energy sources.

All the stakeholders acknowledged climate change and confirmed that this was the general attitude in their organisations. One participant noticed that it did not directly impact their company but that the level of uncertainty due to climate change was one of the important concerns for their customers. Interestingly, one participant with both experience in Europe and elsewhere, noticed that in the latter case there was a "spectrum of beliefs "(e.g.in Australia) and the attitude towards climate change was not that uniform as in Europe.

GROUP II: Renewable Energy sector

The stakeholders from this group provide consulting to the renewable energy industry, including wind, solar and hydropower. Their clients are mainly companies that already have renewable energy (RE) facilities or are planning to invest in it. This group has five participants with the following roles:

- Site and yield specialist
- Renewable energy forecast
- Renewable energy forecast and consulting
- Wind energy resources assessment
- Business Development Manager

Climate change is acknowledged by this group and it presents a part of their business. Some of their clients are concerned about their energy resources and the potential need for energy diversification in the future, e.g. strong reliance on hydropower can make the energy system more vulnerable if precipitation and river flow change in the future.

GROUP III: The research and development (R&D)

This group operates both in private and in public sector. This group encompasses participants with the following job descriptions:

- R&D studying weather and climate impacts on the business
- Two consultants on green energy
- Head of the climate change unit
- Research, development and innovation manager

Climate change is one of the key aspects of the work for this group.

3.1.3.1.2 Climate change adaptation/management of the impacts of climate/weather

GROUP I approached the question about adaptation of the energy system to climate change from a few different perspectives. New renewable energy sources might destabilize the system and it needs to be flexible enough to support this decarbonisation process. Furthermore, climate change and the increased frequency of extreme events might demand more strict safety measures. Thirdly, the system might need to adapt to an increased demand, e.g. due to an increased use of air conditioning. Finally, and depending on the different exposure to climate change and extreme events, some places will need localized hardening of infrastructures, such as better flood defence for substations.

For GROUP II extreme conditions, such as stronger or more frequent wind gusts, can demand different installation characteristics, e.g. better suited wind turbine blades or solar terminal installation.

Management of the impacts of climate and weather is an important aspect for GROUP III, as they are often on the interface between the external data providers and research projects on the one side and the internal needs of the business, on the other. Here, they often strongly rely on external partners, such as research centres, academia and also private companies, as well as climate data providers, such as national hydrometeorological institutions. Research and development focuses on both adaptation of the existing facilities and preparation of new assets for changing climatic conditions.

3.1.3.1.3 Climate change policy

National and regional policies are more important, at least on the short timescale, since they affect local decisions.

When it comes to global climate change policies, GROUP I had diverging opinions; while it did not influence the work of some of them, for others these policies were the main driver of their work, e.g. decarbonisation policy and energy efficiency targets directly influence direction of future investments.

GROUP II thinks that global and national policy can promote certain technologies that then stimulate investments. This policy based push can also dictate the main development line of some of these companies or stimulate the change of focus in some companies from conventional to renewable energy production.

A lot of the GROUP III work is around policy questions, e.g. how to implement Paris Agreement or achieve climate change targets in practice. The energy business depends on the company's internal considerations and perceived opportunities and threats, which are again driven by both the national and international policies.

3.1.3.1.4 Future perspective

The energy sector activities, as confirmed by GROUP III, span all time scales, from short term to medium term (such as seasonal and decadal) to long term time scale.

According to GROUP II, the RE industry "lives in short-term timescale", the participants from this group work on forecasting and are interested mostly in following days up to months.

GROUP I considers medium and long term perspective. Medium term, which is from few months to 10 years, is considered when dealing with operational matters, e.g. planning the maintenance of big production units such as nuclear power plants or large hydropower plants. Also, for selecting new renewable energy sites usually 3-5 years is considered. For those assets with shorter lifecycle, like wind and solar farms, decadal scale is particularly important. If the whole electricity system in a country is considered, than 50 years ahead is the typical length for considering the physical structure of the system.

The long term time scale is also considered for the decisions about long-term investments and about new plants design and commissioning for assets that are made to last at least for 50 years, for instance gas units, nuclear units and hydro power units. Finally, for the safety aspects of nuclear power plants, this time horizon is even longer, looking ahead as far as 2100 or even 2150.

3.1.3.2 *Hazards*

3.1.3.2.1 Hazard type and characteristic

From the perspective of electricity system and research and development, the following hazards are the most important:

- **High temperatures** both affect the demand – increasing the use of air conditioning, and decrease the effectiveness of the system – high voltage cables begin to expand and sag and can come in contact with objects underneath.

- **Heavy rainfall and floods** might render some locations unsuitable for infrastructure, e.g. new floodplains.
- **Coastal hazards**, including storm surges and extreme wave heights might demand new and higher sea defence for the energy infrastructure located on the coast.
- **High winds** cause damage to powerlines, particularly if they happen to be in rural areas where infrastructure is sometimes weaker.
- **Low precipitation** and flow change may affect hydropower production, which is an important regulator of the energy system. This can also deter investments in dam and hydropower plants construction in turn affecting the energy market. The type of the hydropower system depends on the type of flow (it can be with or without the dams). The energy systems that use a lot of hydropower will need to adapt to these new circumstances. In addition, droughts signify less water accessible for cooling energy systems.

Intensity or strength of these events was often cited as the key aspect of hazards. **Length** of heat waves was also considered to be very important. However, the **combined effect** of these events was definitely the most worrisome. Some examples include: a long period of low temperature and low wind, strong precipitation that undermines a coastal defence system making it more susceptible to storm surge, a combined effect of storms and high tides that can lead to flooding of near- and on-shore assets or a combined effect of high temperature and low precipitation. In addition, a **cumulative effect of** these hazards is what in many cases put the energy infrastructure at risk. Similarly, the effect across multiple pieces of infrastructure and the combination of these effects can even cause blackouts.

The **timing** of the events brings the asymmetry to the risk. For instance, positive temperature anomaly in winter will have an impact on the business because they will sell less electricity but will be much easier to deal with than a strong negative temperature anomaly in winter, when the demand is extremely high. Then again, similar negative temperature anomaly would have less impact in the springtime when problems with balancing the supply and demand are not common. Similarly, very low water flow in summer is more problematic than in winter because in summer the water is shared with other usages such as irrigation.

Finally, from the safety aspects, the system should be protected of rare and strong events, e.g. 1 in 1000 years floods. Then again, from the market perspective, cumulative effect is more important, e.g. a single still period will not deter construction of a wind farm on a particular location but rather if multiple events of this type are expected.

GROUP II, in particular those participants focused on the wind energy sector, are concerned with:

- **High winds** – the expected strength of the winds determines the type of the turbine installed in a specific area. Unexpectedly strong winds can render the turbines not suitable for the given location. In these situations, the power plants need to be closed causing loss of wind energy production .
- **Ice** formation is damaging for wind turbine blades and affects the production rate of the wind farms as well. Usually they have to stop the wind farms even if there is good wind because the ice can fall from the blades and harm someone. Icing can also interfere with the aerodynamics of wind turbines.
- **Lightning** is often attracted by wind turbine movements and can damage the blades.
- **Low winds** or wind droughts are of concern if they last for longer periods or occur on a large geographical scale.

Intensity is the most important aspect of high wind. Even a short-lived event of very high wind can damage the turbine. Besides, the events that affect the **business continuity** are of major concern. Thus, **duration of an event** is also important, as the longer the event, e.g. low or high wind, the less electricity is produced, since the plant is turned off. For wind drought, in terms of the affected geographic area, the **scale of the event** is also very important.

3.1.3.2.2 Hazards specific thresholds, recording and tools

Setting climate-related critical thresholds is difficult as an event can be a critical problem in one specific area but not in the other or it is hazardous only when combined with other aspects. Typically, all these hazardous events are case-specific.

In the RE industry, the thresholds are often set by the manufacturers. The blade or the engine producer provides specifications of the maximum and minimum wind that the machine can withstand. The International Electrotechnical Commission (IEC) provides Standardization in the field of wind energy generation systems. Comparison of the wind stream analyses with the maximum wind speed permitted for a certain wind power plant informs their decisions. When it comes to the hydropower plants, again the type of the plant, e.g. characteristics of the dam, depend on the flow characteristics.

There are different sources and ways of documenting weather and climate hazards, from press releases to climate databases ENTSOE (European Network of Transmission System Operators for Electricity) is mentioned as it provides seasonal energy outlook twice a year along with the analysis of the past events. Besides, system operators report all the hazards and each power plant site and RE owner also records events that caused operational problems. The participants are however not aware of any particular database with all the events that have happened.

As hazards tools, the participants from GROUP II mentioned lightning strike maps and icing maps, such as those produced by NASA. Participants also mentioned fire maps as a hazard tool. Besides, one participant uses past climate data for specific extreme events and based on that develops recommendations.

3.1.3.3 *Use of climate data*

3.1.3.3.1 Past climate data

All the participants use past climate data, mainly looking 20-30 years into the past. GROUP I looks into the past data to understand what a typical day in terms of electricity demand and generation looks like and to understand what fluctuation in the demand can weather variables cause. Past data also helps to understand weather patterns. Past climate information is also used as an input in the electricity models and for system planning studies. For planning purposes, historical data is used to construct the equivalent of what would be weather “normal” for particular times in a year and day. One participant from GROUP I uses extreme value analysis, looking into the upper tail of the distribution of all values.

> 30 years worth of historical data to understand what a typical day in terms of electricity demand generation looks like and to understand what the size of the fluctuations in the demand is according to weather variable.

-Risk and resilience analyst

RE forecasters use past climate data to train their models, though this past data may be as short as a single year. Once trained with the past data, the model is combined with forward looking short-term weather forecasts to produce a power forecast. Past data is also used for the future resource assessment and for performance services to show how windy (and why) is the current year of measurement compared to the long term data. Past climate data is also used for extremes analysis, assessing the probability of, e.g., max 10min average wind speed expected in 50 years.

GROUP III uses past data to better understand the climate, e.g. whether a similar event happened before. Data is thus mainly used in research, but also for model calibration. In some cases certain recommendations can be made, e.g. ERA-Interim data is used to reconstruct past capacity factors of wind energy or solar energy.

> An issue with past data is that stations where sometimes moved or relocated and this brings errors to datasets. Or, they changed the equipment and measuring apparatus. This is problem with long dataseries, they need to rely on the models and the surrounding stations to make data harmonization.

- Head of the climate change unit

The participants use various data sources, including observations from commercial companies, data from national hydro-meteorological services, universities, reanalysis datasets including ERA-Interim, MERRA, CFSR, NCEP/NCAR data, E-OBS dataset or specific sources such as Renewables Ninja database. MERRA is the most frequently cited source for the reanalysis data. Wind industry uses data from windfarms, including met masts measurement. Vortex time-series and Vaisala reanalysis data are important data sources for the wind energy. In the case of new wind plants assets, they need at least one year of met mast measurement, while 20 years is the longest reported available mast data. For the planning purposes in hydropower sector, longer timeframe is considered, e.g. past 50 years.

3.1.3.3.2 Future climate data

Future climate data is much less used. The participant working on extreme weather and safety from GROUP I incorporates future climate data in his model. One participant reported that the part of their organization focused on planning the assets structure for time horizon of 50 years, considers using or maybe already uses climate data, particularly regarding protection from hazards, such as floods.

From the RE group, only the participant from the hydropower sector uses data from climate projections, while the RE forecaster consults climate forecast. Other participants from GROUP I and II do not use future climate data. Future climate data would however be very useful for the wind power plant consultancy as it could inform the stakeholders on the type of plant, infrastructural concerns such as type of the turbines and the foundation that are suitable for the future wind conditions in a given region/area.

> The industry lives in more short-term scale, more than academia.

- RE consultant

Participants from GROUP III use more often future climate data in their research. They need to inform adaptation of the existing facilities and for preparing the new ones. For this they need to assess average climate conditions but they also need to estimate climate extremes so that the future assets are prepared. For instance, for nuclear power plants, the evolutions of extremes in particular are already taken into account. Future climate is also needed to understand how the energy systems will behave in the future with larger share from the renewable energy that strongly depends on climate variability. Thus, even those assets that are not climate dependant, such as nuclear power plants, will be impacted in the way they are used and in the way they are operated due to variability on the network caused by more significant share of renewable energy.

As the sources of future climate data, the participants mentioned CMIP5, UKCP, CORDEX, while the forecast is obtained from NOAA GFS and ECMWF.

As for particular metrics or indices, the participants specified wind index, data on number of lightning events per year and number of flashes per square km per year.

3.1.3.3.3 Desirable data characteristics

Data **quality** and **accuracy** are the most important characteristics for all three groups of participants. In addition, **credibility** of data is very important, thus normally only data coming from renowned organisations and trusted sources is considered. **Data format and setup** is another important aspect for the participants from GROUP I and GROUP III, e.g. having data in a format compatible with their software is very important. For GROUP II **consistency** of data is also very important, as well as ease of access. In addition, data **cost** can be an important barrier particularly for smaller RE consultancy companies.

3.1.3.4 *Gaps in current understanding or the tools and information used*

For most of the participants, data resolution is perceived as restrictive at the moment. Finding data in some parts of the world is also challenging, as there data is much more restricted than in Europe or its quality is not satisfactory. In particular, this data is normally not downscaled and thus low resolution presents a gap in knowledge of some geographic areas, such as tropics, where information about convective precipitation is difficult to obtain from these global models with coarse resolution.

GROUP I is also concerned with lack of consistency among climate models, that might show different results. Another concern is related to reliability of the climate models, particularly for the areas that sit on the boundary of two climate zones and thus can be affected by one or the other weather system. In addition, some data although produced is not available or there is a considerable time lag between data publication and the time when the data is made available for broader use.

For GROUP II uncertainty related to data presents a gap in understanding. Data format is an issue for some participants from GROUP III. Both GROUP II and GROUP III recognised that the past data sets are limited, e.g. having datasets for the past 30-40 years would allow better understanding of the RE resources. Besides, some observation data are not reliable or miss continuity, e.g. weather and gauging stations were relocated or the instrumentation was changed all of which can bring errors to the datasets coming from met stations.

3.1.3.5 *Data resolution*

Although all three groups cited data resolution as the main current limitation to using data from climate models, their specific demand for data resolution is rather different.

GROUP I has strong demand for better temporal resolution, e.g. half and quarter hourly data is more frequently cited as their need than a particular space resolution.

Better understanding of the climate change on the regional or sub-country level is another desire. This could help to understand the correlation of energy resources (e.g. wind) across the whole energy system, helping to improve the stability of the system. Individual values in different parts of one system and their cumulative effect is important as well, particularly if we move to a system which is much more reliant on renewables.

> It tends to be that better resolution you have you tend to get better performance in terms of absolute bias reduction.

- Energy systems researcher

For the site analysis, in the case of wind or solar power plants, GROUP II participants need very high spatial resolution, as to determine precise location and capture local phenomena. For this microscale, participants use mast data as they need resolution of more than 50m. For the mesoscale, a few km resolution data is used, e.g. global 3km data from Vortex. For some complex areas, such as tropics, high resolution, e.g. 10km is demanded also for other purposes. GROUP II however is not so demanding when it comes to temporal resolution. Hourly data, and in some cases more coarse, e.g. daily, was specified as sufficient.

3-hourly or hourly data is the preferable time resolution for GROUP III. For some of the research, e.g. in hydrology when looking at the river flow, they need particularly high spatial resolution. Here, they often use point downscaling method.

3.1.3.6 *Type of information from PRIMAVERA*

3.1.3.6.1 General feedback about PRIMAVERA

For GROUP I spatial resolution expected from PRIMAVERA is a desirable one, however, they have very specific demands about temporal resolution (see 3.1.4.5). For GROUP II, very high spatial resolution is of interest – e.g. at the level of a wind farm and therefore, some participants considered little to no added value from PRIMAVERA. However, one GROUP II participant prized high resolution expected from PRIMAVERA and the option to use more climatological data. GROUP III expected that PRIMAVERA would provide improvements in data spatial resolution. Higher spatial resolution will allow them to use more directly the outputs of the climate models, e.g. they can avoid the downscaling step, which adds additional bias and uncertainty. Even with downscaling, e.g. for hydro-meteorological applications with more accurate starting data, better results are expected. Also, for investment and adaptation needs, continuous information between now and 2050 is very important.

3.1.3.6.2 Type of products

Participants from all three groups are interested in having access to raw data. Three participants from GROUP I and one from GROUP III specifically asked for the access to raw PRIMAVERA data. Consequently, derived products are less of a concern for most of the energy sector participants.

> Often we just want access to raw data because that's what is usable for us.

- Energy systems researcher

Visualized information

Visualisation products, such as graphics are not of importance for most of the participants since they prefer to tailor their own graphs. However, the risk analyst from GROUP I would like to use visualised information to more easily communicate to and influence policy makers or business or industry clients. The green energy consultant from GROUP III would also like an online tool with the option to select the region of interest and zoom in.

GROUP II has slightly more interest in visualized information. They mentioned graphical or tabular presentation of wind shear as an example. They also suggested using visualized products to present the results more clearly to the customers without a technical background. Also, in the case when data comes from ensemble of models, visual presentation could help to understand different results from the models.

Descriptive information

In addition to instructions on how to access and download climate data, summary information, particularly on hazards, is also useful for communicating the results to business users. Descriptive information should include the comparison between these new models and the state of the art climate models. Such explanations about the improvements brought by new climate models would make their added value more transparent. Similarly, narratives and case studies would be useful for the RE sector. Guidelines should be aimed at non-technically trained audience and should be rather short-texts documents.

> … we need to then communicate these results to the business users. They are end users, so yes we need to give them the figures but also it's useful for us to be able to communicate this across, so kinds of summary indeed would be quite useful.

- Extreme weather and safety analyst

Technical information

The participants from the energy sector are most interested in technical information. Technical information should include where the data has come from, what are the limitations and applied assumptions. Technical information should also provide background information, e.g. on the scenarios used and the models, comparison between the different models and how they might influence the outputs of the model runs. Access to metadata, the scientific analysis of the quality of data and the associated uncertainties are also mentioned. Information about the physical processes behind some specific phenomena are also considered useful. One participant suggested having technical staff available to provide customer support.

Training

GROUP II would be interested in short training about new data source, e.g. in a form of a webinar or a one day training, which they would prefer comparing to the written guidelines.

3.1.3.7 *Climate change opportunities*

Climate change is generating a huge change within the energy industry and some actors can recognize this change as good. For example, the decarbonisation agenda is a big driver of work for the business and in general, each change can present an opportunity for the business.

For most of the participants, climate change is the premise for the work that they do. Improving the understanding of climate change and translating that information to wider population and decision makers, could imply opportunities. Also, those who make better informed decisions for future planning e.g. the location of new wind or solar power plant, will have an advantage over the others in the business community.

Climate change policy, pushing for more renewable energy is particularly perceived as an opportunity for the RE business. Still, extreme weather events can constrain viable areas and add further uncertainty and risk. In addition, low carbon energy means stronger dependence of electricity system on climate variability. Most of the participants thus agreed that although there would be some winners (e.g. hydropower sector in regions where more precipitation is expected), it was difficult to talk about opportunities from climate change, when there is so much still unknown, presenting possible risk.

3.1.4 Interview analysis: insurance

3.1.4.1 *Introduction*

3.1.4.1.1 Participants characterisation

A total of 25 people from the insurance sector were approached with information about the PRIMAVERA project and a request to fill in a survey which gathers initial information on user needs and requirements. Out of these 25 people, 5 people responded to the survey and all said they were happy to be contacted for a more in depth interview. Three of the five survey respondents then agreed to take part in interviews. A further five interviews were arranged from contacts acquired at conferences, giving 8 interviews in total.

Of the 8 interviewees, four represented insurance and re-insurance companies, three represented risk and hazard modelling and evaluation companies dealing primarily with (re-)insurance clients, and one was involved with (re-)insurance regulation.

Six of the interviewees were based in UK offices and two in Switzerland, although the majority (six) of the organisations undertake work across all of Europe, and half the organisations have global offices.

An important part of work common to all of the interviewees is the analysis of risk of various hazards and perils, including those related to weather and climate. This is required for setting pricing and understanding their financial vulnerability to each hazard. As mentioned by a few of the interviewees, European insurers are required by a European Union Directive known as **Solvency II** to hold enough capital to withstand losses from a 200 year return period event.

Many of the interviewees spoke of **catastrophe (cat) modelling**, which is a common tool used by the industry to quantify risk of a specific hazard. In such models, the insured losses due to a particular hazard are estimated by combining the hazard **footprint** (for example, a map of maximum gusts associated with a particular wind windstorm), with the clients' exposure and policy data. The models can be run using a single event footprint (e.g. a notable past event), or an **event set** – a set of thousands of event footprints – to estimate large return period losses as required by Solvency II.

The interviewees can be divided into two groups which tended to be reflected in their answers about climate data use: (i) those that develop their own catastrophe models (two hazard modelling companies and one re-insurer), and (ii) those that buy/licence catastrophe models, but perform their own analysis on model performance.

All the participants indicated that their companies are **concerned** to various degrees **and acknowledge climate change**. Although some organizations do not have an official statement or policy on climate change, they support the Intergovernmental Panel on Climate Change (IPCC) process and findings or are doing research themselves to understand how it may impact extreme weather events and hence their business. Other organizations have a specific public statement about climate change and are also researching future climate change impacts on risk and how this may affect their organization.

The **attitude of their clients towards climate change varies** depending on the client. It seems that the majority of the insurance clients are concerned mostly with the next few years, while there are also clients who are interested in the climate changes in the next 20-30 years. Of specific interest is whether there are risks currently that are already affected by climate change and flood risk was one of the examples given by some organizations. In addition, it is also of interest whether climate change will impact risks in the next few years.

Although there is great interest in future climate change impacts on the insurance industry, some interviewees indicated that it was not an easy process to include climate change considerations in insurance and re-insurance pricing adjustments.

A specific project which aims to help insurance companies with responding and communicating the risks and opportunities associated with the climate-risk protection gap was mentioned – ClimateWise.

3.1.4.2 *Climate change adaptation/management of the impacts of climate/weather*

Responding to the question whether the **importance of weather/climate hazards will increase** in the future, the interviewees agree that it depends on the peril. For some perils, such as floods, they expect that the risk will increase in the future; for other perils, such as European wind storms, the increase or decrease of the risk is not clearly delineated since research results are not unanimous on all of the future changes. Several interviewees indicated that weather and climate hazards are already very important or the most important perils for their businesses, so they did not anticipate an increase in their importance for their organization's business, or expected that climate change will increase the level of uncertainty around some perils, or said that the risk was already getting worse.

Regarding the **need of their organization to adapt to climate change** and **what measures need to be undertaken for adaptation**, several of the interviewees indicated that they will need to continually reassess weather and climate risk in light of new information, since a large part of work for the insurance sector is analysing risk. For the (re-)insurance companies this change in risk will have to be reflected in their pricing, how much capital they hold, and will affect who they chose to insure. One insurance company mentioned they could give credit to customers for taking precautions such as building retaining walls to protect against flooding. Some of the interviewees indicated that their adaptation actions are closely dependent on the climate science and on the reduction of uncertainty in the projected future changes.

Specifically, when climate change science indicates a greater certainty about the future changes in a given hazard then the companies will have to adapt to these changes.

The responses regarding whether the organizations **have sufficient access to information about future climate change** were mixed. Some of the respondents indicated that they have sufficient access to published information and publicly available data, but pointed out that the data were very uncertain. Some interviewees indicated that they use the IPCC reports, or they were cooperating with academic partners in order to obtain the needed climate change information, but they might not be able to have access to the highest resolution climate change data.

One person indicated the need for a one stop shop with a variety of available information. They also mentioned that the summary documentation on climate change projections could be made more understandable by audiences from the insurance industry.

The negative responses included a comment by one interviewee who specifically pointed out that the biggest issue was getting hold of real weather data and since the information they need was not available from anywhere, they themselves produced the climate change information they needed. Access to data can be improved, stated some of the interviewed participants, but the bigger issue was not whether the data were available but the focus on the longer term projections, while the insurance industry was interested in the next 10 years time horizon. The near-term focus and decadal scale time horizons of the insurance industry are the bigger issue in regards to access to data. Finally, one of the participants pointed out that while they can get public domain meteorological data, what they lack is access to exposure data to understand risk fully.

Regarding the **approaches to manage the impacts of climate and extreme weather in their clients' organizations**, most of the respondents indicated that they used various modelling approaches (catastrophe models, for example) to understand extreme weather related risk. Such models are also used to define prices or which risks to accept or decline. One participant indicated that re-insurers mitigate the impacts for insurers, and they themselves are protected by using retrocessional insurance. As a regulatory requirement for every insurance company, the companies need to be solvent for a 1:200 year return period loss.

Some respondents said that while the impacts were not managed at the moment sometimes they do present their clients with two loss models – one that takes into account the climate changes over the next 30 years and another that does not. One interviewee indicated that depending on the peril, they have a strict scientific approach for some extreme events, while for others they utilize the experience of the underwriters.

3.1.4.2.1 Climate change policy

In their responses regarding the **influence of global and European political decision on their work** the participants were split again with 3 respondents indicating that they were not impacted by these decisions in terms of controlling emissions, while 4 indicated that they support the political decisions and are affected by them. One company was in a position to advise their government about the assessment of risk or regarding government policies to help decrease carbon emissions.

3.1.4.2.2 Future perspective

The interviewed participants indicated that the length of the contracts they are writing often limits the **future time horizons of interest to manage weather and climate extremes**. Standard insurance contracts are typically less than 5 years, so they were most interested in expected average conditions out to this time.

Half of the interviewees stated that there was scientific interest in looking further ahead (the next 20-50 years, and one interviewee stated out to 2100), but many mentioned the difficulty of incorporating the projected longer-term changes within 1-3 year insurance contracts. As one respondent stated, climate change is not the only factor that impacts decisions and operations, but others factors, such as market changes are in play as well.

3.1.4.3 *Hazards*

3.1.4.3.1 Hazard type and characteristic

The highest ranked hazards (rank 5) in almost all responses were the rainfall and rainfall related flooding, coastal hazards, including flooding, and high winds. Snow, ice and frost, as well as droughts were ranked 3 in most cases. High temperatures and heat waves were also rated 3 in several occasions but in one of them the rating was given for cases when high temperatures contributed to increase in fire risk. Lightning and convective storms were given a rank of 3, 4 or 5 with equal number of votes. Landslips and slides were most often ranked as a 2, but two respondents also ranked them the highest. Greatest discord and variation was evident about the low temperatures and cold snaps, which were rated as 1 through 4 by the various respondents.

A summary of the motivation provided by the participants for their rankings and interest in the various hazards is provided below:

- **Rainfall and related flooding, coastal impacts including flooding, high winds and wind storms were rated the highest** – These hazards are covered by insurance policies and in Europe they are responsible for the largest insured losses.

* **Snow, ice and frost** – important for agricultural insurance; there are no big losses from blizzards because they are less frequent compared to floods and high wind events.
* **Droughts** – impact agricultural risk; cause damage and problems for clients; the dryness of the soil leads to subsidence.
* **Lightning and convective storms** - cause damage and problems for clients; important when cause fires.
* **Landslips** - rated highest because bring great insurance loss; or earth movement occurs on a relatively local scale and does not generate large losses.
* **High temperatures and heat waves** – more important when they cause fires; of concern for live stock insurance; or rated 2 because the insurance industry does not provide cover for these events under property or infrastructure insurance but there are some new products for heat waves and droughts.
* **Low temperatures and cold snaps** – rated 2 because the insurance industry does not provide cover for these events under infrastructure or property insurance and they do not have large impacts on property or infrastructure.

One of the participants also indicated that flooding and droughts are increasing in importance as hazards considered by the insurance industry because the industry is starting to provide micro-insurance or index-insurance for developing countries which is indicating some shift in the market.

Regarding the question **which aspects of the hazards bring the most damage**, the respondents mostly answered a combination of factors, including intensity, frequency and footprint size (leading to high exposure of insured assets) while some specifically indicated that it depends on the hazard. Footprint size was mentioned as a particular issue for wind storms. For flooding, one interviewee said that while the mean claim per policy holder for a flood event is larger than for a wind storm, the footprint is smaller.

Most of the participants were able to mention **notable past events**. For flooding, notable events were the 1953 flood; recent flooding in December 2015; the 2007 flooding. Notable wind storms mentioned were 87J (1987), Daria (1990); Lothar, Martin and Anatol (1999); Erwin (2005); Kyrill (2007); Klaus (2009); and Xynthia (2010). One interviewee also mentioned a large subsidence event in the 1990s. Finally, one participant stated that although the industry reacts to historical events, the more important issue is to understand how significant these events are and whether they can happen again.

The impacts from the various hazards are recorded by various insurance companies in terms of the experienced losses and the length of the periods with records can vary from 5-10 years for some new companies to 10-20 years for the established large companies. Most companies have claim filing systems and the claims (all the losses) are recorded and attributed to events. The companies record this information for validation of the catastrophe models and to obtain an understanding of how should the risk be priced. The re-insurance and catastrophe modelling companies do not record such information but receive historical records when a claim from a primary insurance company is submitted; they are second-hand users and the availability of loss data is a problem for them as well.

Most of the interviewees agreed that most of the historical loss data or their company's gathered **data were not public**. Two companies were mentioned, however, who could provide free loss data. Some mentioned that there were companies who could provide anonymized insurance and loss data at a cost.

3.1.4.3.2 Hazards specific thresholds, recording and tools

Several participants mentioned that there were **thresholds** that were being used in their work but few provided more specific information about these thresholds. Some interviewees mentioned financial thresholds, such as the 1 in 200 year return period loss required by Solvency II. For some primary insurance companies, when a loss threshold is exceeded the excess loss is being covered by a re-insurer, while if such a loss exceedance occurs for a re-insurance company they will have to absorb the costs.

Several interviewees mentioned a maximum 3-second gust threshold of 20-25 m/s for wind storm damages, although it was also pointed out that even more important is how much higher than 20m/s is the wind speed, since the increase of loss with wind speed is non-linear. No specific thresholds were mentioned for flood damage.

Regarding the **hazard datasets and tools used in their work,** the majority of respondents indicated that they use data derived from catastrophe and risk models. Such data includes estimated losses due to a hazard and hazard maps. Catastrophe modelling companies also provide historical storm footprints and event sets.

Almost all interviewees mentioned use of observational data or data provided by national meteorological services, such as station or rain gauge data, weather maps (e.g.), and in some cases event footprints. Several participants mentioned use of the XWS catalogue (Roberts et al., 2014), a freely available catalogue of 50 historical European wind storm footprints. Such data is used to verify the results provided by catastrophe models, or is used by the catastrophe modellers themselves in the construction of their own event footprints, event sets and risk analysis.

Re-analysis datasets were less widely used due to their coarser spatial and temporal resolution, and tended to be used by the catastrophe modelling companies. Examples of datasets used are NCEP, ERA40 and ERA-Interim.

One participant indicated that their company has used regional climate model data, while several interviewees indicated that climate model data are often not provided in a format that is easy to deal with.

As one interviewee pointed out, the insurance and re-insurance companies are usually not very acquainted with all of the datasets and are using what the catastrophe modelling companies provide to them. Most of the participants indicated that they are interested in using publicly available data and open-access tools.

Some of the participants pointed out the lack of transparency about the methodologies used by some catastrophe modelling companies to develop the data and tools they are selling. Regarding this aspect the historical output from the PRIMAVERA atmosphere models will provide an independent benchmark for comparison.

One of the interviewees mentioned the Oasis project (https://oasislmf.org), an open source catastrophe modelling platform, which is now starting to create a data hub that will contain a mixture of free and paid-for data for use by the insurance companies.

3.1.4.4 *Use of climate data*

Responding to the question whether they are using **climate data (raw data) or information (derived products)** in their work, almost all interviewees indicated that they **use products derived from climate data** in their work, referring to their use of catastrophe models outputs. As stated by one participant, this is because they need to know the financial impact of the hazard, and such information is incorporated into these models.

Several interviewees also stated use of raw climate data (observations or re-analysis products), either for use in building their own catastrophe models, or for catastrophe model validation (see section above). Another derived product mentioned was event footprints, which some companies buy ready-made, but others prefer to construct them themselves from raw data.

One interviewee stated they prefer to run their own climate models rather than using ready-made datasets, so they can tailor it specifically to their needs. Some participants indicated that they are using both, raw data as well as derived products in their work.

Many of the respondents stated that they did not use **hazard related metrics or indices** in their work. When used they tended to be financial indicators, such as loss from a storm, rather than hazard related indices.

Others interpreted the question as which weather climate variables they used (rather than derived metrics/indices). Variables specifically mentioned were wind speed at the earth surface, flood depths, size of hail stones, and size of storm surges. One participant mentioned wind storm severity indices (similar to those mentioned in Roberts et al., 2014) are used to select some of the storm footprints from historical observations for use in catastrophe modelling.

3.1.4.4.1 Past climate data

All of the interviewed participants said that **historical observations were used** in their companies.

While some are using observational and re-analysis data (see above), others are using also qualitative/anecdotal descriptions of past events for the past 150 years (e.g. Lamb 1991) to make recreations of historical events to understand what is the biggest historical storm.

Explaining the reasoning **why past data are being used**, the participants indicated that the historical data and information provide an understanding of the characteristics of historical events, such as frequency and spatial patterns, provide a context for the future, and allow the simulation of stochastic event sets.

Historical data is used also for catastrophe model validation, for risk management and for pricing. The past data is also used to challenge the industry for regulation purposes – to see how the various companies performed during some extreme events, how the cat models performed, to challenge the industry processes and understand their limitations.

Answering the question **which past time period is of most interest**, the interviewees generally stated they wanted as far back as possible, but to when the data is still reliable. They are limited by the length of observational and re-analysis datasets (typically 30-40 years), but most would prefer to obtain data for periods longer than this.

3.1.4.4.2 Future climate data

Some of the interviewees indicated that they do not use currently future data but would like to, or they are using published research such as UKCP publications, or they have used future data for other areas in the world but not for Europe yet.

Others stated that they have used future data, and one participant even indicated that they are developing their own forecasts of future climate where they look at 5 years out in the future. The same participant also mentioned that they use a lot of historical data to predict the future climate, because the climate models do not simulate storms of the right strength or size to be used on their work hence the basis of the prediction has to be historical data.

Those that indicated that they have used or are using **future data** listed the following **types**:

- Regional climate model simulations from the ENSEMBLES project up until 2100;
- Seasonal forecast data;
- CMIP5 raw data to use as input in their forecasting models;
- Climate change scenarios;
- Regional projections.

To explain why some interviewees are not using future climate model data or what **issues** exist **regarding the use of future climate data** the participants pointed out:

- the uncertainty around the future information;
    - to circumvent this they are using probabilistic estimations which are based on the present day and extrapolation from that baseline;
- the future projections often focus on what will happen around 2100 instead of 2030;
- the future projections focus often on climate means instead of extreme events;
- the CMIP5 GCMs have coarse resolution;
    - they can be used for basic studies of a storm index, for example, but not for modelling;
- it is very difficult to act on any information that is further ahead from about 5-10 years in the future;

Answering the question, **what are they using the future data for**, some respondents indicated that they would use the future data for stress testing the catastrophe models and the metrics they need would have to be directly applicable to the hazards themselves, for example, in terms of severity or frequency of storms. Other said that the information from published research is used to make decisions on whether there is a need for pricing action. In summary, the future data is needed to understand future risk; to be able to justify why are we including or not including CC.

Reflecting their answers on future perspectives in Section3.1.4.2.2, the **future period of most interest** was generally stated to be the next 5-10 years. A few participants mentioned interest in the next 25-50 years to have a long term horizon, although this information would not necessarily advise policy making. One participant mentioned climate projections from the middle to the end of the 21st century would be useful for stress testing.

3.1.4.4.3 Desirable data characteristics

For more detail on this section please refer to the sections above and below.

3.1.4.4.4 Gaps in current understanding or the tools and information used

Gaps in understanding:

A few participants mentioned a list of 13 questions compiled by a catastrophe modelling consulting/evaluation company. The list is available at . Of these 13 questions, interviewees specifically mentioned the following:

- Understanding the limits to European wind storm severity/what the footprints of the most damaging wind storms would look like.
- Whether recent trends seen in winds/flooding are due to natural variability or climate change.
- The correlation between winds and floods.
- Better understanding of wind storm clustering in time.

The interviewees also mentioned:

- Impacts of climate change, for example how climate change will affect maximum rainfall, frequency of rainfall, or river flows. This could be expressed as a change in return period levels (adjustment factors).
- How to resolve biases in climate models regarding extreme events when the historical data is very limited.
- How to implement the effect of climate change on risk when only looking up to 10 years ahead.
- What is the most appropriate data to use to try and understand risk at present?
- Catastrophe modellers are using some statistical downscaling to assess risk at a local scale, but this is done behind closed doors and the methods are not clear;
    - Need downscaling methods that would be appropriate to use to be developed by academia;
- Understanding the damage and vulnerability uncertainty;
- Understanding the secondary impacts of storms – such as coastal flooding;

One of the participants, however, explicitly stated: “Do not believe there are gaps in understanding; we have access to journals so that we can understand what is going on.”

Gaps in data or tools:

- Higher resolution historical re-analysis data: for wind; climate simulations at 25km resolution or higher. One interviewee mentioned needing 100m resolution along the coasts.
- Long simulations/alternative realisations of present day climate to generate hazard footprints /event sets for catastrophe models. Since Solvency II regulations require estimation of a 1 in 200 year return period event, a reliable estimate requires thousands of years of data.
- Freely available atmosphere and ocean models which companies can run themselves.
- Continuous wind measurements, maximum wind speed over a short amount of time and quality controlled data which is publicly available;
- Exposure and vulnerability data – the damage that the event could cause. These are the main uncertainties which dwarf that of the hazard.

3.1.4.4.5 Data resolution

The participants often acknowledged the mismatch between the spatial and temporal scales they are working at and the spatial and temporal scales of the available climate and weather data: "We are insuring buildings at the metre scale and climate models provide data up to 25km, ERA Interim has 80km resolution – this is not good enough."

More information about the desirable spatial and temporal scales of the climate and weather data needed for the insurance sector operations is provided in the sections that follow.

3.1.4.5 *Type of information from PRIMAVERA*

3.1.4.5.1 General feedback about PRIMAVERA

Answering the question **whether the 25km (on average) resolution of the PRIMAVERA models will be useful,** the majority of the respondents indicated that this is a step forward and in the right direction. In addition they provided the following comments:

- It is an improvement to 100-200km currently available from climate models, although the finer resolution the better. A few interviewees mentioned floods in particular would need a finer spatial scale (e.g. to capture convective rainfall, complex topography).
- Extremes can be better captured at high resolution.
- 25km is useful if there is a relationship between changes on this scale and smaller scale extremes.
- For wind storms, at 25km you have enough information for further downscaling to capture extremes.

- For precipitation: at 25km resolution you are getting a fairly good grasp of the frontal precipitation, but I do not know whether it is enough to get the convective events that you get in summer.

One of the participants was confident in their conviction that the higher resolution at approx. 25km would not be that useful. This participant stated that although increasing the resolution is a step forward, their view was that a climate model at 25km does not simulate realistic hurricanes, storms, rainfall, tornadoes, or convective storms in general.

Usual spatial scale of focus

Most of the interviewees mentioned they usually focus on much smaller spatial scales than 25km. Flood models/maps tend to have extremely fine resolution (less than 10m), whereas for wind storm models/maps their grids are slightly coarser (1-4km). Sometimes variable grids are used (1km in high exposure areas to 25km in less exposed areas).

A few participants mentioned point locations, since weather station/river gauge data are used as inputs to models. On the other hand, one participant also mentioned using 0.5 degree data from global climate models.

Time resolution

The responses to this question depended on how it was interpreted. Three interviewees mentioned seasonal or annual information, as they are concerned with the insured losses on this timescale. However, the remaining interviewees acknowledged that the input hazard data used to estimate these losses has a much higher time resolution. For flooding, daily to six-hourly data is used. For wind storms, the three second gust was mentioned, although usually a maximum value over 6-72 hours is used. One interviewee mentioned for storm surge they need 6 hourly data.

3.1.4.5.2 Type of products

Regarding obtaining **guidance and descriptive documentation** from PRIMAVERA the participants in the interviews indicated that they were interested in:

- Descriptions of future changes in rainfall amounts, wind speeds, and extreme events in general, including where the research feels confident that we have gone beyond noise, and at what time scales you expect to have these changes. This could be in the form of a 4-5 page digest report with the option to obtain the full technical information.
- High level information on how the above have been calculated.

- Descriptive information on whether the present day models all show similar behaviour to that seen in the past 20 years for storm activity, and what impacts it will have in the next 5 years;
- Model uncertainty – to be included in the metadata;
- Information split by country;
- Analysis of the biases in terms of wind simulations compared to an observational reference;
- How strong the wind and flood correlation is in the model;
- Whether further statistical downscaling on the model data is acceptable;

Answering the question about what **data and technical information** the participants would like to obtain from the PRIMAVERA project, they indicated:

- Several participants requested documentation around the datasets and models that produced the data, including:
  - formats of the data and how to change the formats to another one if it is not provided;
  - full methodology about how the data has been developed, its limitations and assumptions, and alternative methods that other people might use;
  - model validation reports;
  - a description of the wind and gust parameterizations

Derived data products requested were:

- Wind storm and flood event footprints (maximum 3-second gusts or cumulative rainfall maps) for use in catastrophe modelling, for present and future climate. If possible the event sets would represent hundreds to thousands of years of data, although one interviewee mentioned just having the top 100 events would be useful.
- Present and future storm tracks.
- Probabilities of windstorm intensity exceeding values at certain locations, preferably on a post code or city level, but even a country level would suffice.
- Changes in regional rainfall return period levels (hazard maps).
- One participant who was interested in insurance losses through burst pipes requested information on changes in average number of days per year below –4°C.

A few participants requested the raw output of 3-second gust and rainfall, although this is not possible through PRIMAVERA.

Regarding the acceptable **file formats of the data**, most participants are able to work with netCDF, although this would cause difficulty for some. Other commonly used formats are geoTIFF and ESRI ArcGIS shapefiles. One interviewee mentioned plain ASCII format files containing latitude, longitude, time and hazard, would be most accessible.

Visualized information

Many of the interviewees mentioned they would be interested in visualisations of the derived data requested above, although the majority of interviewees stated they would require the data behind the visualisation for it to be of any use. The following visualisations were mentioned:

- Hazard/return period maps of rainfall and wind speed.
- Visualised storm/flood footprints.
- Metrics or visualizations of any extreme event, description including variability and trends;
- A website that can help with plotting of some information similar to: NOAA Coast which allows plots of tropical cyclone tracks, to calculate track density within an area etc.

Training materials and activities and format

- To discuss what other people are doing with the data; to have central contact address would be useful so that we can ask questions;
- Having a user support email address;
- Training on 2-3 of the formats that the meteorologists use and how you can turn them into a format that we use; A workshop would be useful to show what data is available; Help to understand the data and the formats;
- Useful to have a workshop where you can talk to people or have the opportunity to call;
- Some training sessions, 1-2 hours, face to face would be very useful around the product, the science, the assumptions and limitations.

3.1.4.6 *Climate change opportunities*

Considering any **potential positive impacts of climate change** for their organizations some of the respondents indicated that, yes, there may be greater need for insurance and re-insurance especially on the flood side, or in general, any increase in certain kind of extreme weather risk is potentially good business. On the other hand there may be a reduced risk from some perils, for example, from frost events in agriculture. Others also indicated that while the risk of some extreme events may increase it may go down for other extreme events.

3.1.5 Interview analysis: transport

3.1.5.1 *Introduction*

3.1.5.1.1 Participants characterisation

12 interviews were conducted for the transport sector. Interviewees comprised transport users, consultants working in the field of transport, and academics researching transport-related topics. There was reasonable coverage of transport modes and role types though not all combinations were represented (see Table 2). Unfortunately there was no representation specifically from urban transport (e.g. metro/subway) in the interviews, though there was some representation in the survey. In addition there was geographic bias in the transport sector interviews; coverage in the survey was better, but we were limited by those who consented to be interviewed.

Table 2: Role type and transport mode(s) of focus of the transport sector interviewees (12 in total). The geographic scope of each interviewee's discussion (country level, Europe level, global level) is indicated in brackets.

		Transport mode			
		Land transport (road and/or rail)	*Aviation*	*Marine / ports / waterborne transport*	*All modes*
Role type	*User*	2 (country)	3 (2 country, 1 Europe)	1 (country)	–
	Consultant	1 (country and Europe)	1 (global)	–	1 (global)
	Academic	2 (1 country, 1 global)	–	1 (country)	

All participants felt that their sectors / organisations are aware of, and acknowledge, climate change. However, there was variation in how organisations and sectors were acting upon it. Some perceived that this variation depended on legislative drivers (e.g. the existence or otherwise of country-level laws requiring action on climate change) or economic drivers (e.g. the financial capacity of an organisation to act upon climate change, or the financial capacity of a country to support adaptation activities in that country). One participant noted the difficulty of incorporating climate change into existing economic decision making frameworks such as cost-benefit analysis.

Other points highlighted by participants included:

- The link between present-day experiences of extreme weather and the future impacts of climate change
- The importance of climate change for long-lived assets, typically transport infrastructure.

3.1.5.2 *Climate change adaptation/management of the impacts of climate/weather*[3]

All participants felt that weather/climate hazards could become more important for their work, their organisation, or for the sector in future. Several participants related their current weather management experiences and pondered how this would need to change under a changing climate. Others noted that the long life of some transport assets was a factor. There was also reference to the bigger picture, with not just the management of “their” part of the system, but also the possible effects of a changing climate on the wider transport landscape, e.g. through changes in demand.

There was consensus on the need for the transport sector, and organisations within it, to **adapt** to climate change. Some participants commented that this was already happening, with one person stating that the sector was forced to adapt as a result of its experiences of extreme weather; and another stating that adaptation was needed, whether reactively or by foresight.

There were differing views on adapting to existing hazards being sufficient, vs. a need to be aware of other hazards which had not previously been an issue but which climate change could cause to become one. This linked to participants’ descriptions of current weather management activities – for some, the management of particular “typical” hazards was a business-as-usual activity, but it is the rarer and/or more extreme events that created bigger problems, due to lack of preparedness. One participant also referenced the extent to which institutional memory affected weather management and risk perception, stating that the perceived biggest issue for their organisation varied in time according to what had been experienced most recently (for example, cold winters vs. mild/wet ones).

Specific activities for managing *weather* included:

- Use of real-time and forecast data and information in influencing decisions about operational activities – for example, use of CCTV cameras to identify flooded roads so diversions can be put in place
- Development of operational management plans for severe weather events (e.g. ceasing or not commencing a particular operation if particular weather thresholds are forecast to be exceeded; pre-emptively closing parts of the network if certain conditions are forecast)
- Hazard-specific management plans (e.g. reducing the safety risk from possible rail buckling in hot weather

3 Note also that several other projects have assessed weather risk and its management for transport in Europe – examples being EWENT (EU FP7), WEATHER (EU FP7), MOWE-IT (EU FP7), and TRaCCA (UK, rail only).

- Development of seasonal strategies for managing different weather throughout the year
- Use of bespoke warning systems at known weather-sensitive locations
- Use of traffic management systems
- Creation of criteria (either subjective or objective) defining “normal” and “abnormal” weather conditions, with normal conditions being the ones under which services should be available and operating normally, and abnormal conditions being the ones under which disruption should be expected
- Logging weather-related incidents in formal or informal databases, to monitor their number and severity over time
- Ensuring good asset management processes are in place

Specific activities for managing *climate* included:

- Undertaking vulnerability / risk assessments
- The development of organisational plans, strategies and roadmaps for climate change adaptation and mitigation, either proactively or in response to legal / regulatory requirements
- Reviewing operational and design standards containing weather/climate-related elements (e.g. design temperature ranges, design rainfall amounts) to check whether they could still be appropriate in future
- Using historical weather data together with future projections to determine whether new assets need to be built differently from existing assets

Participants had many different reactions to the question about whether organisations had sufficient **access to information** on climate change:

- Some felt that information was lacking, with one person explicitly citing resolution as an issue;
- Some felt that access was available to those who required it;
- Some felt that knowing what to do with the available information, rather than having access to it, was the bigger issue.

Participants in the aviation subsector noted that subsector’s greater focus, to date, on the mitigation agenda (i.e. related to impact of aviation on climate) rather than the adaptation agenda (i.e. impact of climate on aviation); respondents felt that this has been changing in recent years, however. There was relatively little reference to mitigation activities from non-aviation participants, despite the fact that these activities are happening across other subsectors.

There were multiple references to **interdependencies** between transport modes, e.g. an extreme event affecting one mode badly but not another, allowing users to switch from the affected mode to the unaffected one; or the inability to reach a transport hub such as an airport or port if the road/rail links to it were affected.

Related to this, a small number of interviewees highlighted the **global connectivity** of the transport system, and that – even though we had asked them to focus on Europe as PRIMAVERA is looking at European climate risk – it was difficult to consider European transport in isolation, as there could be knock-on European transport impacts from outside Europe.

Relative **times of emergence** for hazards were referenced by some participants. One participant felt that climate change was incremental and that adaptation could be achieved through existing weather management processes. Another noted that sea level rise was a slowly evolving hazard and that there was therefore more time to adapt to it than to other hazards.

Participants were asked to highlight **specific past events** that had been impactful; among the examples quoted were several different flooding events; the 1953 storm surge; the cold winters of 2009/10 and 2010/11; specific windstorms and – for the UK in particular – the winter of 2013/14 with multiple successive windstorms; and particular lightning events.

3.1.5.2.1 Future perspective

Participants' future time horizons of interest for weather/climate management again varied:

- Timescales of **hours to a couple of days ahead** were referenced in the context of operational weather management.
- One participant referred to a timescale of **1-2 years ahead** for tactical planning.
- Organisational planning cycles tended to operate on timescales of **5-10 years ahead**. Examples cited were the awarding of operating licences or other government-imposed regulations.
- Longer timescales tended to be referred to by participants as "strategic", with **2050, 2085, 2100** being mentioned as specific time horizons used in future planning, and future timescales of anywhere between **25 and 200 years ahead**.
- Multiple participants linked the timescale of focus with asset management, and specifically the **lifetimes of different assets** (e.g. 100-200 years for bridges and tunnels)
- One participant expressed a wish for planning efforts to relate the time horizons more to the specifics of the transport system (or subsystem thereof) and less to the timescales prescribed by governments for climate change assessments.

To some extent the variation depended on interviewees' specific job roles, and how much experience they themselves had of management at particular timescales (e.g. those with more knowledge of operational management discussed the short term in more detail, and those with more knowledge of planning discussed the long term in more detail).

3.1.5.3 *Hazards*

3.1.5.3.1 Hazard type and characteristic[4]

Several hazard types were discussed with the interviewees; those who completed the relevant survey question were reminded of their answers and asked to discuss and explain these in more detail.

<u>Road and rail</u>

In general the biggest issue for road and rail was perceived to be rainfall and rainfall-related flooding. The next highest were low temperatures, snow/ice/frost, wind, and earth movement (landslides). There was no real distinction between low temperatures and snow/ice/frost when participants discussed their impacts.

Moderately rated on average were high temperatures, drought, and lightning/convective storms. Coastal hazards including coastal flooding seemed to be the lowest-rated, though there was a lot of variation in the rating and most participants acknowledged that this was (by definition) highly location-specific.

- **Rainfall and rainfall-related flooding** was the top ranked hazard for road and rail. Participants referred to the disruption/damage caused by flooding, for example its spatial extent, and its frequency of occurrence. Flooding may affect roads and railways directly, or have indirect effects, e.g. on signalling equipment, depots and stations. Where flooding arises due to swollen rivers, it may also cause damage to structures, e.g. by scouring the foundations of bridges. Surface water flooding can also affect roads and railways by overwhelming drainage. The safety risk from flooding is more easily managed on the railway, whose use is controlled by the system operators, but the more autonomous nature of road users may pose an additional risk (that is, road users may still attempt to use a flooded road, whether or not official closures have been imposed).
- **Snow, ice and frost** can affect the railway in a number of ways. Snow above a certain depth must be cleared from the tracks in order to allow the safe passage of trains. Points may freeze, disrupting train services. For electrified railways using a conductor rail (third rail), icing of the third rail disrupts the traction current, leading to service disruption. Other issues include snow ingress into some types of locomotive engine, the potential for rails to crack or break, avalanches impinging onto the track in mountainous regions,

[4] Note that this section has been completed using information from the interviews and additional sectoral knowledge of WP11 colleagues.

passenger and staff slip/fall hazards at stations, and icing in tunnels. For roads, these phenomena can cause safety issues, with roads needing to be cleared of snow and surfaces gritted to reduce the risks posed by ice.

- **High winds** can put high-sided vehicles at risk of overturning on road bridges and exposed roads. There is a similar risk to freight wagons on the railway. For electrified railways using overhead line equipment (OLE), high winds can bring down the OLE or blow objects onto the OLE, disrupting train services. Both road and rail transport can be put at risk (in safety and disruption terms) by trees and other debris being blown onto the road/railway.
- **Earth movement** (e.g. landslides) can affect both roads and railways, particularly in countries with ageing infrastructure slopes, which would not have been constructed according to any design standard. (Participants also linked this phenomenon to excess rainfall.) In mountainous regions, rockfalls may be induced by freeze-thaw cycles.
- **High temperatures** on the railway can affect track geometry (rail buckling); windows of opportunity for maintenance on ballasted track; the operation of electronic equipment (e.g. for signalling) inside small buildings or lineside cabinets; and passenger/staff thermal comfort at stations and on board trains. For roads, degradation of the road surface is a possibility in hot weather.
- **Drought** can affect road and rail infrastructure built on certain substrates, such as peatland or clay soils. In drought conditions these substrates may dry out and shrink, exposing foundations or causing structural degradations or instabilities.
- **Lightning and convective storms** can damage electronic equipment such as that used in railway signalling. One participant rated this highly because of the difficulty both in predicting where a strike would occur and in the mitigating actions that were possible for lightning. Lightning can also start vegetation fires at the lineside. Lightning was generally not consider a hazard for roads; any reference to convective storm impacts on roads related to the very heavy rainfall involved rather than the lightning.
- **Coastal hazards**, including coastal flooding and coastal erosion, were noted as impactful for locations in which roads and railways were adjacent to the coast, by virtue of their potential to disrupt services and damage infrastructure.
- **Other hazards: vegetation-related** issues were also highlighted in terms of planting choices for infrastructure slopes and whether such choices would remain appropriate under a changing climate. Such vegetation can be used to stabilise slopes, as well as increasing biodiversity. This is in addition to the disruptions experienced on some countries’ railways during the annual leaf fall season. When fallen leaves becomes crushed onto the rails by passing trains, a slippery film can be created, resulting in adhesion issues between train wheels and the rails, which poses a safety risk.

There was no consensus on whether intensity, duration or frequency of events brought the most damage. Participants made the following suggestions:

- “Slow-onset” events like heatwaves are perceived as more manageable than “faster-onset” or instantaneous events like flash floods and landslips – due to there being more preparation time
- The event intensity/duration/frequency is only one factor and that the level of impact depends on the intersection of that with factors such as how busy the network was at the time of the event
- The impact of an event depends not only on the intensity/duration/frequency of the weather event itself, but on the time it would take to partially or fully restore the service after the event

Several participants discussed spatial extent of events, particularly in the context of flooding – it was noted that the most impactful floods (in an aggregated sense) were those which spanned a wide area. They would typically involve impacts on multiple transport subsectors and indeed on other sectors, and hence could not be resolved by individual transport organisations but rather via a multi-agency response.

Aviation

Broadly speaking, the biggest issues for aviation were perceived to be high winds, snow/ice/frost, and rainfall/rainfall-derived flooding, followed by lightning/convective storms and high temperatures. Coastal hazards were deemed impactful, but by definition only for coastal locations. Drought and earth movements were perceived to be less of a problem for aviation. Low temperatures were rated highly, but when participants discussed their ratings their comments around low temperature usually involved snow, ice and frost, so low temperatures have not been discussed separately here.

- **Snow, ice and frost** affect operations, as (for example) aircraft need to be de-iced, and runways cleared of snow. These phenomena can also affect access to airports themselves.
- **High winds** pose operational problems, resulting in delays and diversions to alternative airports; and may pose a risk to construction operations at airports. In the longer term, changes to wind climatology around an airport (e.g. changes to the prevailing wind direction) was considered a risk, as airport runway directions are chosen based on wind climatology information. Some airports have multiple runways to address this.
- **Rainfall and rainfall-related flooding** were cited as impactful for airports in tropical areas, though not especially as an issue for Europe. However, flooding may disrupt access to airports by affecting the ground transport links to the airport locations.

- **High temperatures** pose a heat stress risk to personnel working on exposed parts of airports, such as the apron. In extremely high temperature conditions, there can be an issue with aircraft takeoff and climb, as air becomes less dense and there is not as much lift. Some airports around the world have longer runways to accommodate this issue.
- **Lightning and convective storms** pose a safety risk to air travel, and sectors (geographic divisions of airspace) may be closed in severe convection conditions. Lightning and convective storms can also put personnel on the ground at risk. Some airports where these phenomena are common have "lightning sheds" where ground personnel (such as those working in aircraft maintenance) can take shelter in a storm.
- **Coastal flooding** – such as that which could arise from storm surges – was deemed to be an issue for those airports close to the coast, of which there are several in Europe (though participants did not cite any examples).
- **Other hazards**: the Northern Hemisphere polar **jet stream** affects transatlantic flight routing. Since the flow across the North Atlantic is from west to east, westbound flights need to avoid the jet stream where possible, while eastbound flights are able to travel with the jet stream, thereby reducing flight times and saving fuel. Flights are dynamically routed to take account of the jet stream position.

There were diverse opinions on the issue of whether intensity, frequency or duration of events was most impactful. **Intense** rainfall leading to flooding was cited as problematic for airports elsewhere in the world, as it resulted in airport closures and long recovery times. Disruptions from flight diversions and cancellations were discussed by participants, but there were differing views on whether **duration** of an event or **frequency** of events would be the bigger problem in terms of recovering from such events. A link was drawn between event **frequency** and financial impacts specifically. The **combination** of events was also cited as a problem.

Marine / ports / waterborne transport

The hazards identified for this sector were high winds, coastal flooding, rainfall and rainfall-related flooding, snow/ice/frost, lightning and drought.

- **High winds** can disrupt port operations, which are often conducted using large cranes. Such operations cannot proceed in high winds. High winds can also affect shipping operations, such as manoeuvring ships on and off berths. In very windy conditions these operations cannot be undertaken simply because the wind forces induced on the ship are too large to handle, even with multiple and/or large tugs. Wind direction is an important factor for approaching or leaving ports depending their orientation.

- **Coastal hazards** are of obvious relevance for ports. Coastal assets may be damaged directly by floods. Flooding of ports can disrupt ship access to the ports, as it may not be possible to secure them properly. Flooding at the port can also affect connectivity to other transport modes (e.g. road and rail). Changes in sea level can affect the clearance under structures, such as bridges, at ports. The processes which lead to coastal flooding can also lead to coastal erosion, which may in turn change coastal morphology and affect navigability.
- **Rainfall and rainfall-related flooding** can increase river flow, which can affect river navigation – it is more difficult to carry out ship manoeuvres, such as turning, under higher flow conditions, and transit times may increase if travelling against an increased flow (though conversely they may decrease if travelling with the increased flow).
- **Snow, ice and frost** can affect the road and/or rail access to/from ports. In turn, this may lead to suspension of port operations, because goods would not arrive or there is nowhere to store them. At high latitudes, sea ice also affects navigation, with icebreakers possibly being required.
- **Lightning** can be hazardous to sensitive electronic navigation systems.
- **Drought** poses a risk to inland waterways transport, as decreasing river levels can only be accommodated up to a point, depending on the under-keel clearance of the vessel.
- **Other hazards: visibility** is an issue for navigation. It is possible to navigate most ships in zero visibility, but navigation and manoeuvring ships alongside an installation in zero visibility becomes more hazardous in busy shipping areas or in areas which are difficult to navigate. **Tidal flows/currents** are also an issue for navigation, in an analogous way to that described above for river flows.

3.1.5.3.2 Hazards specific thresholds, recording and tools

The question about use of particular **hazard datasets and tools** yielded a range of responses, with the following being mentioned:

- Weather data gathered by the organisation itself (for those that have their own *in situ* meteorological recording equipment);
- Publicly available weather forecasts and weather-related forecasts (e.g. flood alerts), such as those available from a country's own national meteorological or environmental organisations;
- Publicly available sources of *data* (as distinct from forecast products themselves);
- Chargeable sources of data;
- Industry-specific/customer-specific weather forecasts/tools;
- Site-specific instructions or documentation, which may be based on local expert judgement and experience;

- Country-level climate change projections, in countries where these exist (two such sources were referenced by name);
- IPCC climate projections and reports.

In terms of organisational **recording** of data about hazards/impacts, this seems to be rare, and in many cases is done at a local and/or informal level, and not necessarily as a matter of routine. A couple of examples of more formal record keeping, and of such records being used subsequently in some kind of analysis were cited. Participants with experience of working with these kinds of records (where the records have been collected by other organisations) noted some shortcomings in the records, however. For example, such data are typically collected for monitoring safety and/or performance, rather than with the specific purpose of understanding weather impacts, and hence were not always usable for the latter purpose.

Thresholds were more of a challenge; people accepted that there may well be thresholds in weather-related quantities that would be relevant for them, but few could give specific values for these.

The following specific critical thresholds were mentioned by participants:

- Visibility – some ports impose restrictions on ship movements if visibility drops below ½ mile (marine, ports, waterborne)
- Rainfall – storm water runoff system should be capable of draining the water from either a 1:10-year or 1:50-year rainfall event depending on the situation (land transport)

The following specific **metrics, indices and indicators** were mentioned by participants, though not in conjunction with specific values of any thresholds:

- Wind speed & direction combined (marine, ports, waterborne)
- Flood alert levels (marine, ports, waterborne)
- Intensity-duration-frequency curves for rainfall (land transport)
- Temperature threshold above which roads need to be closed to heavy vehicles – value not known (land transport)
- Wind alert levels, and a wind threshold above which it is advised not to drive empty trucks – value not known (land transport)
- Critical rail temperatures for managing rail buckling risk (land transport)
- Flood levels on the railway track, above which trains may not operate (land transport)
- Performance metrics – number of trains arriving on time, degree of road congestion (land transport)
- Saturation points – monitoring of earthworks stability (land transport)
- Wave heights – monitoring of coastal infrastructure (land transport)
- Rainfall intensities

- Rainfall amounts and translating those into flood flow rates
- 100-year and 500-year rainfall events
- Rate of change of sea level rise

Some participants noted that company or industry documentation may contain thresholds, but these were felt often to be site-specific rather than widely applicable, or only known by the people to whose roles they were relevant. There were organisations that had done work to look at thresholds more quantitatively, but these were in the minority. It is likely that further user engagement could elicit specific values for thresholds, assuming there were no confidentiality issues with sharing these.

3.1.5.4 *Use of climate data*

Interviewees were asked whether their focus was more on using climate data (raw/direct model outputs) or climate information (processed/tailored data, or products derived from such data). Almost all said that their focus was more on information. Reasons cited for this largely focused on a lack of appropriate skills for working with data, and a lack of available resource to do the more intensive work that interviewees perceived to be necessary for using the data directly. It was also stated that information was easily available, so there was no need to work with data; and that data was less useful for the higher-level stakeholders who needed materials to be in an accessible and simple format.

The few interviewees who used data were those working in academic roles rather than in consultancy or end-user roles.

3.1.5.4.1 Past climate data

Participants were asked about their use of past climate data and/or information. They focused mostly on the data element here. Most participants stated that they use past (historical) climate data, though some said that this was only used in very specific cases rather than routinely. Quoted uses of historical climate data included:

- Deriving thresholds for impacts
- Informing decision-making / understanding how such data can support decision-making
- Informing new infrastructure builds
- Logging past events to see how often action is taken
- For planning / “lessons learned” purposes
- Exploring trends and relating the norms from last century to new norms

One participant felt that such data may be pulled together internally within particular organisations, but that there was little or no resource to analyse the data.

Most participants obtained historical data from their country's / city's official meteorological service or from another meteorological provider. Some participants' organisations also collect their own meteorological data.

The historical time periods of interest varied. Some participants used only data from the relatively recent past (~5-15 years); one participant felt that "organisational memory" was relevant for this, i.e. that the events of interest were those within the memories and experiences of the people working there, unless an event had been so severe that regulations had changed because of it.

Others looked back over all available data (which could be anything up to ~100 years), and others only used data for specific past events.

3.1.5.4.2 Future climate data

When asked about their use of future climate data and/or information, most participants said that they did use this material. One participant expressed a wish to use future data/information, but felt that it was too early in the evolution of their climate change adaptation strategy to be doing so yet.

Quoted uses of future climate data and information included:

- As a topic of interest only
- Raising awareness and understanding
- Improving the specification of a future investment
- Planning significant capital projects
- As part of a climate change adaptation study (either planned or completed)

Quoted sources of future climate data and information included:

- Scientific journal articles
- Country-level climate projections and associated reports
- IPCC climate projections
- Information on the internet (details were not specified)

There was wide variation in the future time periods of interest, but many participants linked it to asset life, and the fact that this could be very long for transport assets. Values ranging from 10 to 200 years ahead were suggested. Participants also linked this to the degree of foresight of their organisation or sector. (See also Section 3.1.3.1.4 "Future perspective".)

3.1.5.4.3 Gaps in current understanding or the tools and information used

The following gaps in understanding and/or knowledge were identified:

- One participant felt there was a gap in knowledge (in their transport subsector) of what climate change information is available and to what extent it is relevant, but felt this gap was closing with time.
- Gaps for specific hazards were identified:
  - At the weather timescale, the uncertainty of cumulonimbus forecasting, and forecasting of thunderstorms/lightning.
  - At the climate timescale, research on the projected changes to the jet stream.
- How to move from having access to and/or understanding of climate projections towards understanding their implications for the transport organisation in question, and for its role in the wider transport system.
- Related to the preceding point, how to move from having a good qualitative understanding of impacts towards a quantitative evaluation of these, e.g. financially or operationally.

The following gaps in tools/information were identified:

- Scale and resolution – lack of availability of data at an appropriate scale, e.g.:
  - At the weather timescale, using regional-scale forecasts/warnings for a specific site, resulting in reduced trust when the events that are warned about do not happen at the site.
  - At the climate timescale, using low-resolution climate model data or regional summary projections for a point location.
- Translation from averages to extremes – many climate projections provide information presented as averages, whereas most users are interested in extremes, whether for understanding current and future impacts, or for designing new assets to be resilient in future. Countries which have their own projections may provide information about extremes but this is not available by default for all countries.
- Language and applicability – publicly-available tools are often by definition generic rather than tailored to a specific need or sector, and use generic language that can be interpreted differently by different users (e.g. one person's "very high risk" is another's "medium risk").
- Tools for vulnerability assessment and adaptation – one participant felt that generic risk assessment / adaptation resilience planning information is available in their sector, but that there is limited information on what the specific issues are, and how to manage these.
- Tools for economic impact – these are rarely constructed in such a way as to be able to take climate change into account.

Only one participant did not feel there were any gaps in their organisation's understanding or the tools/information used by their organisation.

3.1.5.4.4 Data resolution

The topic of **resolution** presented some interesting discussions (see also Section 3.1.5.5.1). Participants were positive about increased **spatial resolution** but some noted that even this was far from what they needed. For example, participants noted the need for very high resolution (~tens of centimetres – tens of metres) for some applications, like understanding wind loading on cranes or modelling flooding of particular roads. There were also comments on the challenge of linking this kind of extremely fine scale modelling to coarser scales (e.g. specific road to city-scale).

Contrasts were mentioned between the topographies of different countries and how this affected the geographic variation in weather experienced across these countries, and by extension whether increased resolution would add any further information in the countries where there was little geographic variation.

Participants from countries which have their own country-level climate projections were sometimes doubtful that PRIMAVERA would add value in terms of spatial resolution, as the spatial resolution was similar between PRIMAVERA and those existing projections.

One participant from the aviation sector highlighted that aviation was interested in spatial resolution not only horizontally, but also vertically through the atmosphere.

With regard to **temporal resolution**, participants often confused this with lead time, despite our efforts to word the question more carefully (having experienced similar misunderstandings in the survey). In any case there was once again a wide range of responses. References were made to the use of real-time information and hourly data in weather forecasting to support operational activities, and also to a desire to obtain fine-scale information when conducting a historical study of a particular incident.

In terms of climate timescales, many people felt that the general guidance offered by projections/trends at a seasonal or annual scale, and/or multi-year/multi-decade averages, was sufficient for their purposes (this was true across subsectors). There was reference to “the distribution” and probabilistic elements. One person did not think that anyone in their organisation would use daily (and it is assumed, by extension, sub-daily) climate projection data for their work.

One participant highlighted the “jump” between commonly-used baselines for climate projections (e.g. 1971-2000) and projection information (which often starts around ~2020s). This can lead to information which looks unrealistic and also to potentially inappropriate use of the information to make predictions at shorter lead times than climate projections allow.

In general it was the most technically-minded participants who noted any potential value of sub-daily information from PRIMAVERA, and these people tended to be the ones who were already using daily data. These participants linked temporal resolution with the relevant timescale of the processes and/or impacts concerned (e.g. sub-daily and even sub-hourly data were needed for extreme precipitation / surface water flooding; perhaps daily/weekly information for open water storage and processes related to river flooding – but this was not at all important for longer-timescale processes such as those related to groundwater). Only one person explicitly stated that their work had been constrained by existing data resolution limitations, and that they had worked with daily data because sub-daily had not been available. Another noted that some countries have access to sub-daily climate data, but others do not.

3.1.5.5 *Type of information from PRIMAVERA*

3.1.5.5.1 General feedback about PRIMAVERA

Most participants felt that information at a higher spatial resolution would be useful to them or their sector (see also Section 3.1.5.4.4). Many drew parallels with their spatial scale of interest – for example, referring to specific locations (usually ports and airports); the spatial heterogeneity of road/rail infrastructure (long in one dimension, short in the other). Some referred explicitly to higher-resolution information being better for decision-making/targeting of resources, and to wanting resolution to be as high as possible; others were more circumspect, noting that increased resolution was a step in the right direction but that there were limits on how useful repeated increases in resolution could be in practice.

Spatial scales of interest varied considerably. Participants discussed these in terms of both their own sectoral interests (e.g. location of infrastructure) and more geographic terms (e.g. scale of weather phenomenon or geographic feature):

- Small scale: localised infrastructure (e.g. ports, airports, railway track sections, road sections...); specific types of weather event (e.g. squalls, thunderstorms...)
- Moderate scale: sub-country scale organisational sub-units (e.g. regional units of a country-wide company); sub-country scale river catchments; small units of airspace ("sectors")
- Large scale: whole countries or country-wide organisations; whole seas or regions of ocean; large-scale regions of airspace; river catchments spanning multiple countries

Some participants' roles also involved the consideration of multiple different spatial scales.

The following topics were raised by the more technically-minded participants:

- Whether PRIMAVERA data / outputs would be spatially coherent (this was considered beneficial)
- Whether greater spatial resolution would increase the reliability of the data or whether some of the robustness of the models might be lost with higher resolution

3.1.5.5.2 Type of products

Participants in the transport sector generally required some assistance with exploring the options for types of products that PRIMAVERA could provide – many did not have any especially well-formed opinions about this aspect, and simply said that the various categories of information would be helpful or useful without specifying details. Some people also focused on what were the important qualities of the information, rather than the nature of information itself.

Several participants mentioned the delivery of information and products via an online platform/tool/interface.

The following four categories were probed explicitly. We chose not to limit the participants' views by explaining what was technically possible; as a result, not all of the suggestions below are necessarily achievable by PRIMAVERA.

Guidance and descriptive information

> *I want a lot of guidance and descriptive information – the basis for the information that's being provided, what factors it did and did not include, to understand how it can be appropriately applied.*

– Researcher

> *A fact sheet [...] was quite well received because it was simple, in 5-10 minutes you have got the basic idea.*

– User

It was suggested that guidance and descriptive information would be useful for people in senior roles, whose time was often limited. Such material should be concise and focused. However, more technical users also wanted to receive guidance, which would need to be more detailed.

Suggestions included:

- A 30-second summary of the project
- "Myth-busting" about the inevitable effects of climate change
- A narrative for generalists
- Data-focused guidance, about:

    - What data are available
    - Background to the climate change scenarios
    - What is, and is not, represented well within the data; where uncertainties come from; how uncertain information can still be used in future planning
    - What can be done (i.e. what is possible) with the data; what the data were intended to help improve; how specific sectors can use the data
    - Acceptable, and non-acceptable, use of the data
- Fact sheets providing succinct summaries
- Guidance material should be accessible via a website / dissemination platform so it can be obtained whenever needed

Data and technical (specialised) information

> *Data on the extremes is most important.*

– Consultant

There were lots of perspectives on data and technical information, in varying detail depending on participants' roles.

Suggestions included:

- Access to the data
- Location-specific climate data
- Key overview data over different timescales
- "Scenarios":
    - Scenarios of frequencies, durations, intensities of events
    - A number of scenarios out to 2050
- Extremes:
    - Information about events with long return periods (1:10 out to 1:50 years) rather than the 99th percentile
    - Future severe rain events to use in drainage assessment
- Specific hazards:
    - Future temperature envelopes
    - Floodplain envelopes, flood levels, flood velocities
    - Potential risk of combined hazards
- Information that can be incorporated into sensitivity analysis
- Technical knowledge on how to translate climate data/information into operational/infrastructure impacts
- Providing the whole bandwidth of future scenarios and uncertainties, so consultants / organisations can decide on what to use

Visualised information

Anything which illustrates the problem rather than lots of words!

– User

There were a range of views on useful visualisations:

- Time series of how particular variables change over time – useful for adaptive management (when might something happen and could action be taken in time to avoid it)
- Maps:
    - Most useful if sophisticated and highly granular
    - Quick access to maps of particular variables
    - Europe-wide maps that have consistency across national boundaries
- Visualisation of what could happen and what the impacts could be on a sector, organisation, or asset
- Side-by-side visuals comparing today and 30 years' time
- Geospatial information that can be integrated into GIS
- Scale was considered important (an example was given: "will my local area be flooded?" vs. "will my house be flooded?")
- Infographics for quick and easy dissemination of information
- Tools:
    - Screening tool to allow rapid screening of infrastructure for particular hazards
    - Something that integrates with (and/or looks visually similar to) weather forecasting tools, to build trust

Training materials and activities

Training would be good because we can then target different parts of our business...having training materials levelled at different audiences would be useful.

– User

Many participants felt that training was useful but that it needed to be tailored to specific audiences, discussing the difference between high-level and/or generic training, which would be suitable for senior managers, and more detailed and/or focused training, which would be welcomed by (for example) engineers and designers working in a particular sector or subsector.

The format of training materials / activities was considered important. One participant suggested “away days” for senior people, as this would encourage focus on the task at hand. High-level briefing notes were also considered helpful for this audience.

Online training/courses and videos were suggested as helpful from a general user perspective. Powerpoint format was also suggested.

For specialist users, seminars and face-to-face workshops were highlighted as helpful, since these allow two-way communication and questions. One participant encouraged sector-focused training engagement in particular; another questioned whether the uptake of such activities in their subsector would be sufficient to warrant developing them (despite being generally supportive of the idea themselves).

One particular country’s risk assessment / adaptation planning cycle was referenced, and it was suggested that any PRIMAVERA outputs that could be tied in with this cycle would likely encourage participation in workshops.

3.1.5.6 *Climate change opportunities*

Some participants felt there could be opportunities from climate change. The most common one mentioned by participants was the potential for climate change to alter demand:

- Through changes in the desirability of particular locations as tourism destinations or freight hubs (those who mentioned this highlighted that it would be an opportunity for some and a threat for others, however)
- By lengthening the tourism season in some locations, which could smooth out current demand peaks

An anticipated reduction in the number of cold events (and associated snow/ice) was thought by several participants to be beneficial, though one noted that the reduction in numbers of these events might reduce preparedness for the cold events which do still happen.

One person speculated that the future climate might be less variable, and proposed that this could make resilience investment decisions easier (by focusing on the more commonly-experienced issues rather than the less frequent ones).

Another highlighted the link between improving short-term resilience and long-term climate change adaptation, suggesting that the need to adapt was making people think more about how to do that in ways that can also enhance short-term resilience.

Other participants were reluctant to suggest any climate change opportunities, and some noted that even if they had stated opportunities, these were not sufficient to offset the threats.

3.1.6 Interview analysis: water

3.1.6.1 *Introduction*

3.1.6.1.1 Participants characterisation

Seven interviews were conducted with the stakeholders from the water sector. The sample includes four researchers in hydrology, two water managers, and one consultant in water resources and hydropower.

The work of the four hydrologists included research on water resources, extreme climate, hydro-meteorological risk, and urban water management. The sample included both academic researchers (1) and researchers from governmental agencies (3) that support policy makers, and water managers concerned with wide range of issues, including water reservoirs, water distribution in agriculture, and flood protection.

The work of the water managers is focused on (i) long term water regulation for hydropower production and dams safety and (ii) the climate change adaptation in the water sector. The consultant works on the full range of hydropower related issues, from designs and construction of hydropower plants to water resources management.

3.1.6.2 *Climate change adaptation/management of the impacts of climate/weather*

The interviewees consider that climate change is something that we are already facing. Climate change, according to some of them, will not necessarily bring new risks but will rather exacerbate the existing ones. Water users have always been familiar with land use changes caused by urbanization and farming activities. With the climate change there is however another stressor in terms of how they manage water for the multipurpose water use, taking into consideration the water-food-energy nexus. The climate change research in the water sector can inform water-related decisions and strategies, and benefit the society and the economic sectors that are dependent on water.

All the participants said that climate change is acknowledged in their work and their institutions. Similarly, their stakeholders or customers are most often interested to know what changing climate might bring in the future.

One participant, however, reported that water managers, such as channel water managers and irrigation managers, are more concerned with climate change than the hydropower sector. Another participant also reported the lack of flexibility of the hydropower system, which follows long-standing rigid rules that do not provide for climate change adaptation. Another participant noted that in their country, mostly small companies manage the integrated water systems and often lack the capacity to address climate change related issues.

The water companies, on the other hand, are already adapting their practices to the changing climate. For example, consulting weather forecasts to take precautionary actions in the case of extreme events – if a major precipitation event is anticipated, they assure that the storm tanks are empty, trash screens are clear, and deploy flood barriers as needed. After two extremely cold winters, another recently adopted measure was provision of additional valves to make leaks more “localised” and telemetry installations for remote monitoring of leaks on the pipes.

The academic researcher reported their work on a comparative world-wide study of climate change impacts on water sector, which demonstrated that although the severity of the hazards is growing, the overall impact is reduced due to significant reduction of vulnerability.

3.1.6.2.1 Climate change policy

Climate change policies can stimulate a dialogue between climate researchers and practitioners. In this way, the topic does not stay only within the researchers but also goes to the political and societal debate. The subsequent policies then make things more concrete and also help information dissemination.

According to the hydrology consultant, the global climate change policy still does not play a major role for the hydropower sector. What would make a significant difference, according to this participant, is a political decision to enforce climate adaptation studies at development stage of large infrastructures, such as hydropower.

3.1.6.2.2 Future perspective

The interviewed stakeholders from the water sector consider different timescales when managing climate related issues. Still 2050 and 2100 were two years most frequently mentioned.

Operational perspective is usually five years and the strategic one is 25 years. For the infrastructure management and new infrastructure planning, mainly 10 to 20 years period is considered. For long-lived assets, such as sewers and coastal long and short sea outfalls, this period is longer, usually 50 years.

For the academic research, a longer time-horizon is often considered, until 2100. The context however, will also determine the horizon, e.g. the Sustainable Development goals are assessed until 2030, and some other assessments are performed for 2050. The type of input information can also determine the future period, e.g. the water manager for hydropower uses the national climate projection data that span to 2100.

Interestingly, according to the interviewed consultant, the clients from the hydropower sector are interested in shorter terms, usually 2040 or 2050, while water authorities in Europe tend to look far into the future, up until the end of the 21st century.

3.1.6.3 *Hazards*

3.1.6.3.1 Hazard type and characteristic

Types of hazards

The major hazard for the water sector, as confirmed by all seven participants, is **extreme precipitation** and related **floods**. For (urban) water managers, connective storms – short, sharp rainfall – makes problem by overwhelming drainage network and combined sewers. If storm tanks are overwhelmed, the sewage is discharged straight to the river untreated. Longer period rainfall and flooding in general (from rivers or at coast) can inundate assets, such was the case from November 2016, when the water potabilization system located near the flooded river was inundated. Extreme rainfall and surface water flooding is one of the biggest problems also for the hydropower production. An example is extreme precipitation in the winter that accelerates the melting process and can easily cause floods.

For one participant from the water management, ice and snow related hazards significantly affect their work. An example is leakage related problem that appears when cold periods are prolonged or when rapid changes happen around the freezing point. During the two consecutive very cold and snowy winters, they had a problem of not being able to find leaks under so much snow. Low temperature and freezing conditions affect some water treatments, e.g. a sewage treatment is inoperable in cold due to freezing equipment and the reduced ability of bacteria to break down the sewage.

One hydrology researcher noticed that **water scarcity** is becoming a problem in their region that has traditionally been water rich. People, however, are still not acknowledging this problem. From the experience of one participant, many water managers deal with both droughts and floods. Moreover, they usually go from one extreme to the other. Prolonged droughts and low flow conditions are also a significant problem for the hydropower production. In general, **changes in the runoff periods** can significantly affect the hydropower production and management practices. One example is the case of a very cold spring in the Northern Europe, which slowed the snow-melting and reservoir-filling rates. As the result, there was still some snow in the reservoirs in the summer. The combination of high summer temperature and precipitation caused the remaining snow in the reservoirs to melt rapidly and over-filled the reservoirs with water, rendering the standard water management process inadequate.

In addition, **high temperatures** during winter over the Northern Europe accelerate the snow melting process, producing extra water in a period when the lowest flow is expected. The damage caused by such high flows in the winter is often greater than in the summer, especially because broken ice can flow down the river.

The knock-on effect of **high winds** was cited as important by one interviewee.

<u>Hazards characteristic</u>

For floods, which are very quick processes, **intensity and frequency** are the most important aspects. In terms of coastal hazards, which also have sudden onset, **intensity** is a crucial aspect as well. One interviewee emphasized that the physical characteristic of the watershed – whether it is flat, mountainous, large, big round or more rectangular, – also play a role in terms of the response of the catchment to the surface flow runoff.

During the intensive and quick events, water managers do not have time to apply right measures. For hydropower, in terms of floods, **intensity** is significant as large reservoirs are designed to withhold/stand against certain amount of water.

Furthermore, for water scarcity and droughts, which are often slow processes, the **duration** and **frequency** are more important than intensity. Moreover, a distinction has been made between droughts that occur during one season or a year, and long lasting, multi-year droughts. Also for low flows, the **duration** is the most important characteristic but the intensity and frequency count as well.

Finally, the **combination of different aspect** is relevant. The combination of the scale and duration of an extreme event will define its effect. In addition, if an extreme event follows another, it does not leave enough time in-between to recover, making the second event even more damaging.

3.1.6.3.2 Hazards specific thresholds, recording and tools

Each river in Europe has defined thresholds that are related to the frequency of flood events. In the case of larger rivers, the thresholds are for specific river sections, e.g. there are thresholds related to the inundation of the critical parts, such as large cities or important infrastructure along the river. These flood thresholds are based on the frequency of flood recorded so far. Normally, more than 100 years return period is considered as the design level for the flood risk assessment to build dikes and other protective infrastructure. In some cases in Europe, this recurrence interval is 500 years. Again, the catchment characteristics are very important. Also, some floods can be spatially distributed, and although not intense at one point, by covering the large area, they strongly affect that catchment. In addition, socio-economic characteristics of the catchment – whether it is an area with existing economic or societal issues – defines the overall vulnerability to the flood.

For the channel water management along rivers, there are also well defined critical thresholds that relate to flooding of certain areas.

In urban areas, design specifications exist for the drainage system and these specifications are based on certain rainfall events happening once in every 100 years.

Freezing conditions between 0°C and -4°C is the threshold for pipe leakage.

Still, each event is specific as summarised by one participant:

> Each event is unique and we try to learn from data, from weather or climate or hydrological data, and to capture these events that in fact are all unique like fingerprints.

- Hydrology researcher

Incidents are recorded by the water company, but often not well quantified. Specifically, incidents that affect homes, such as flooding, are recorded. It is difficult to determine the root cause of an incident because they are often a combination of weather event with other factors, e.g. equipment failure. So it is difficult to categorise something as a weather incident. In the UK, there is the Flood and Water Management Act from 2010 and water companies provide information to the Lead Local Flood Authorities, which publishes the reports openly on the DEFRA website.

One more participant reported that data is recorded but not organized in a simple way to be extracted. Another participant reported not being aware of a public database in their country with a record of all the floods.

A hydrology researcher reported performance of post-event analysis. A strong flood or drought may affect river morphology and basin response and even disturb measurement devices. Thus, many aspects need to be considered and changed in terms of hydrology modelling systems. For post-event analysis, they collect quantitative data on discharge, rainfall and other aspects.

The hydropower consultant is however, unaware of such a practice in hydropower sector.

Some of the reported hazard tools include the Met Office's Hazard Manager, flood alerts from the country's environmental agency, radar from Meteogroup, Met Office Fire Risk Index for wildfire risk, Soil moisture deficit indices, for water resource planning and Drought severity indices.

3.1.6.4 *Use of climate data*

Stakeholders from the water sector primarily use climate information and processed data but would also be interested in some raw data, e.g. raw data on precipitation.

Particularly for some consultancy work, they can often rely on available information, as some clients are just interested in e.g. "whether the inflow to their hydropower plant will rather rise or decrease with climate change".

However, to run their models, such as hydrologic or water management or hydropower models, our participants need 'raw' data, including time-series of observation data and also data from climate models.

All participants use past climate data. Future climate data is mainly used in research, while two interviewees reported the use of future climate data for planning purposes.

Main variables of interest are precipitation and temperature. Besides, for flood risk and water scarcity assessment humidity and wind speed are also considered. In the hydropower sector, discharge data from the rivers and streamflow data, as well as evaporation are used. Finally, snow models need sun radiation data.

3.1.6.4.1 Past climate data

Past climate data is used to learn the response behaviour of a catchment related to the past events, to understand the processes such as runoff and watershed response to precipitation or temperature.

> We are usually going to learn from our observations. Nature is our laboratory - some kind of memory of what happened. When something happens today or in the future, we can also put it against what happened in the past

- Hydrology researcher

Past climatic data is also very important for the model validation and calibration. Then, once the model has learned about the catchment, understood how input and output are related, it can then be used with future climate data. A hydrologist reported that they also used neighbouring catchment data when data on the analysed catchment was lacking.

The main data they need in the hydropower sector are discharge observations, precipitation observations, information about temperature, and evaporation.

For the agricultural water demand, another participant reported using data about humidity, soil moisture and precipitation, in order to calculate water demand.

The considered period in the past significantly varies depending on the purpose of the data use. To understand the natural hydro-climatic variability and the behaviour of a catchment, data as far in the past as possible is considered. For urban water analysis, this period is shorter. They consider past 30 years. For the design flood calculation, past 20 years is considered and the period is even shorter for the model calibration for inflow forecasting, about 10 years.

The participants mostly obtain data from the national hydro-meteorological services. Besides, some also use publicly available observational datasets like satellite data or gridded observation datasets that are interpolated from the stations, such as precipitation, temperature, and evaporation observations. Another example is the publicly available global discharge observations database at the German hydrometeorological service.

3.1.6.4.2 Future climate data

Future climate data is mainly used in research. Most of the participants reported that future data was not used for decision-making. One participant, however, reported the use of future data in design flood calculations. The other participants reported the use of future climate data for water resource management planning and sewer network modelling. Furthermore, future climate information is used to set the overall context of some strategies, such as climate change risk assessment.

Future climate data is obtained from the national services. Some participants also use summarised information from IPCC. One researcher reported the use of the CRU TS dataset and PIK’s (Potsdam Institute for Climate Impact Research) website that integrates data from several global hydrological models, including the climatic data used in these models. Another participant uses UKCP data and CONVEX data for projections of extreme rainfall change under climate change.

3.1.6.4.3 Desirable data characteristics

Trustworthiness is an important characteristic of climate data. Good practice examples of use of data can help build trust in the provider.

The novelty of data was cited by one interviewee because some customers want to have updated information on the latest climate modelling.

Contacts and ease of access are important determinants for selecting certain data. Also the availability and pertinence in terms of the region you are dealing with is mentioned by a few stakeholders. Availability of observation data for some parts of the world is limited. Also the quality and accuracy of data, particularly of local observations, is not satisfying in some cases. In addition, climate models are more specific for some areas or regions or some weather regimes and they do well in these cases but maybe not in the others.

In some cases, the use of particular sources is recommended to the companies, e.g. national data, in others the project itself demands certain type of data.

3.1.6.4.4 Gaps in current understanding or the tools and information used

Two participants commented that there is no gap in information, but on the contrary, there is too much information. However, this information is not in a unique place and such a reference website would be useful.

Another participant is concerned that there is more data produced than is made available, e.g. CORDEX data contains only some simulations of certain modelling groups.

Other gaps in current tools and information include:

- Gap in understanding weather impacts,
- Availability of future flood risk maps and future sea level maps,
- Difficulty to cope with different emission scenarios and uncertainty,
- Lack of information with high reliability and local information,
- Data with better resolution, both temporal and spatial resolution,
- Decadal information,
- Tailored climate/weather information for different types of users. There is a variety of users in catchments with different scales and types of catchments, and they have different objectives and challenges,
- Lack of local data for bias correction,
- Uncertainty when it comes to discharge and river flow,
- Snow measurement.

3.1.6.4.5 Data resolution

Stakeholders from the water sector are in need of very high spatial resolution. They are less demanding when it comes to temporal resolution, since daily resolution usually suffices.

The spatial scale of interest for water sector researchers and managers is a catchment. Catchments however can be of varying sizes, but the higher resolution is preferable in any case. In addition, some participants need climate data in the urban scale, e.g. for the urban flood risk analysis. In this regard, a few participants commented that 25km spatial resolution is too coarse for their work. 25km spatial resolution would be however useful for the water resources research, according to our participants.

In terms of temporal resolution, for water resources analysis, usually yearly data is considered. Assessment of water demand and availability for different purposes demands monthly or daily data. Hydropower managers also usually consider monthly and daily data. One participant commented that for sewer modelling, subdaily data is used.

3.1.6.5 *Type of information from PRIMAVERA*

3.1.6.5.1 General feedback about PRIMAVERA

Spatial resolution of around 25km is considered too coarse by most of the participants, except for the water resources analysis for which this resolution would be an added value.

One participant was concerned with their computing power and possible limitations to handle large datasets that this higher resolution models will produce:

> We have very normal computers and we are getting increasingly large datasets. It is difficult for us to manage the amount of data that comes with large ensemble of daily data for a large region. Therefore, I think it will probably be very difficult to use data with higher resolution.

\- Consultant

This participant thus suggested that PRIMAVERA should provide tools for clipping or restricting the data in order to select subsets of datasets, e.g. just for a small region of interest. (In fact, such tools already exist, e.g. ADAGUC, http://adaguc.knmi.nl/)

Another comment was to compare PRIMAVERA outputs with the data from other sources, such as UKCP18.

3.1.6.5.2 Type of products

Descriptive information

One interviewee considered that it may be more interesting for users to know the temporal distribution of the climate, “if there will be longer period of dry climate, if there will be longer period of wet, if there will be alternative wet and dry, dry and wet or more often dry period in terms of time variability”. So, to describe the time variability of climate and to transform it to consequences for water.

The other participant expressed interest in descriptive case studies.

Technical information

Some participants are also interested in receiving processed data, i.e. they would like if the principal analysis of the data is already done and made available. An example is data bias correction, in particular as many water managers do not have capacity to conduct this step on their own.

It would also be useful to have information on how the data was produced and the implications that the way of producing the data has on its use. This would provide an overview of what the data producers think the data can be used for and where it should not be used. In other words, explanation about where these products really have an added value because of their higher resolution should be provided together with the data.

For another participant, the key is to have consistent metadata, so that the user has an idea of the underlying processes and information on how the data was collected, as well as the methods behind its production.

One participant, however, reported difficulty in working with the large variety of model runs. This interviewee would thus like to have access to ‘selected’ model runs, though it was not clear on what criteria they should wish to make a selection.

Visualized information

The water sector stakeholders are fond of receiving visualized information. A few participants expressed interest in mapping products of the climate indicators, such as number of days above or beyond a certain threshold.

Among figures and maps, the water manager listed flood risk maps, sea level and coastal erosions visualizations, Arctic ice cover, North Atlantic Oscillation, and wildfire risk across Europe.

Although graphs do not necessarily provide the exact information the users need, they are still considered informative and useful products. In particular, visualized information accompanied with more technical data is considered useful.

Training

Only two participants commented about training materials and activities. One suggested organisation of training about broad topics either at sector level or targeted for specific communities (e.g. water resource modellers, flood risk modellers). Another suggested topic for the training was “Communicating climate science”. The other participant stated that trainings might be useful but the timing of the workshops/trainings is very important – they need to coincide with the time when you need this information. Webinars and recorded webinars were a preference of these two interviewees.

3.1.6.6 *Climate change opportunities*

We received various answers to the question whether there could be any positive impacts or opportunities related to climate change.

The following opportunities coming from the changing climate were perceived:

- Fewer cold winters;
- Reduced pipe leakage caused by freezing conditions;
- Reduced gritting costs;
- Increased efficiency of sewage treatment, since the temperature enhances bacterial processes;
- Improved hydropower potential thanks to more rainfall and more inflows, e.g. in the Northern Europe more water available in the winter would improve energy production that is normally low in this part of the year, and make it more balanced throughout the year.

The researchers and hydrologist saw the indirect opportunity from climate change, coming from new business opportunities and more work in their research centres.

The third view was that climate change combined with many other stressors that impact water and land management would make the situation more complex, presenting lot of challenges both for the research and for the application. Similarly, in many developing countries more damage is expected from flooding, droughts and coastal hazards.

3.1.7 Interview analysis: agriculture

3.1.7.1 *Introduction*

3.1.7.1.1 Participants characterisation

We interviewed 3 participants in the agricultural sector, all working in the Netherlands. Two participants are agricultural researchers whose work is focused on adaptation of the agricultural sector to climate change. These two researchers did not participate in the PRIMAVERA survey. One interviewee works in the consultancy sector and provides the agricultural sector with extreme weather warnings. Most customers of the consultant are farmers in developing countries, therefore the experience of this participant is not always relevant for European user needs. Some of the answers, e.g. related to which hazards affect their work, are reflecting the need of their customers, while others are from the perspective of the organisation or company. The researchers highlight that they often speak to farmers with higher education since those are more interested in climate change and science in general and therefore their perspective might be biased and not representative of the ‘average’ farmer.

All stakeholders acknowledge climate change and confirm that this is the general attitude in their organisations. However, they also notice that the farmers are sometimes sceptical towards climate change. Farmers often say that weather varies from year to year and that was also the case in the past. Furthermore, fluctuations in the market are more important for them than climate change. For example, in a bad year the potato harvest will be low, but the potato prices will increase. However, farmers that are well informed and higher educated are more interested in climate change and also see the need to adapt.

In addition to the interviews a literature analysis was done to obtain additional information. In the following sections we will therefore include some relevant results from previous user requirement inventories[5].

3.1.7.2 *Climate change adaptation/management of the impacts of climate/weather*

All participants think that climate-related hazards will become more important for the sector and that the agricultural sector needs to adapt to climate change. Different options that are mentioned to adapt are altering varieties/species to those that are

[5] Information from inventory user requirements in the Netherlands for Agriculture (crop production, animal husbandry, fishing, forestry) Bessembinder et al., 2011 KNMI-TR 317

more resistant to climate hazards, altering irrigation plans, and altering the timing and location of agricultural activities.

All participants say they have sufficient access to information about climate change. But the researchers indicate that structured information on Europe-wide scale (downscaled scenarios for different countries) is hard to find since it is distributed over different websites.
Individual farmers also have enough access to weather and climate information. They search for adaptation information in agricultural magazines. E.g. each year has some climate extremes (heat waves, heavy rain) and in these magazines farmers that are well adapted to these changes are interviewed, thereby providing information about climate change adaptation to other farmers. Farmers that are searching for information about climate change can also find it. However, not all farmer are interested.

3.1.7.2.1 Climate change policy

The researchers mention that the political decisions are important for their work. The Paris agreement determines how they will tailor their research: they will compute the impact on the agricultural sector based on the targeted increase in temperature. It makes their work more visible to policy makers.

About 10-20 years ago, agriculture was seen as a polluting sector and farmers were not interested in climate mitigation goals. Today, farmers are willing to contribute to climate change mitigation, but not at the expense of their economic interest. Farmers are mainly driven by cost reduction, fuel reduction is therefore an interesting possibility for mitigation. Even though in the Paris agreement there was not much attention for the agricultural sector, some big food companies also want to reduce their impact on the environment and acknowledge that the agricultural sector contributes to greenhouse gas emissions. By (financially) encouraging farmers to reduce their environmental impact they aim to reach the mitigation goals set in the Paris agreement (‘Cool Farm Alliance’). This is also partly consumer-driven, since more and more consumers want to reduce their environmental footprint. In this way, individual farmers are also (indirectly) impacted by climate change policies.

The consultant thinks that his organisation is indirectly influenced by policy decisions, since political decisions can raise climate change awareness among farmers and their interest to adapt.

3.1.7.2.2 Future perspective

All interviewees mention that, farmers in general, are used to plan ahead, especially when it comes to long-term investments. For example, before they invest in new drainage systems or new machinery they want to know if it is sufficient for the next 20 years. Only in the last 5-10 years they started to take climate change into account as an additional factor. For example, when farmers buy new land, some farmers only buy it if its elevation is sufficiently high so that they can cope better with high amounts of precipitation in autumn without having to buy special equipment (such as heavier machinery) for harvesting.

How far farmers look into the future is also dependent on their age. Older farmers at the end of their career are interested in the next few years but not in 2050. Younger farmers look much further into the future. They want to be prepared for the future and want to adapt their company to future changes.

3.1.7.3 *Hazards*

3.1.7.3.1 Hazard type and characteristic

The researchers mention that in general for Southern Europe heat waves and droughts have the highest impact. For Northern Europe new pests and diseases are more relevant. There are also problems through an asynchronisation of climate and phenology of the plants. For example, when there is frost during the flowering period the apple harvest will be much lower.

Storms are important as well, but there is not much information on the adaptation side. For instance, it is not well known at what wind speed grains will ledge, since it is also dependent on other factors such as soil moisture.

Farmers typically look at historical events, such as the drought of 1976 over Central Europe and the British Islands, to rate the impacts of particular hazards. Historical impacts are not formally registered within the sector. However, newspapers and farmer magazines can give information about historical impacts. Some researchers coupled this information to meteorological data, but it is very expensive to do this type of research.

Possible impact of climate change that came forward (including results from previous user requirement inventories) are:

- With a **higher CO_2 concentration**, the stomata of plants do not have to open so far, which causes the plant to lose less moisture. This may lead to a relatively lower need for water and higher biomass production.

- Effects of **higher temperatures**:
  - The development of many (agricultural) plants goes faster, which can lead to an increasing production (due to longer growing season or higher production per day) or a decreasing production (faster ripening, therefore shorter growing season).
  - Above a certain maximum temperature (varies by species) there will be a decrease in production.
  - Higher potential evapotranspiration, requiring more water.
  - Chance of heat stress on animals and plants.
  - Influence on quality of products.

- Possible effects of a **change in precipitation**:
  - Possibility of increased drought, less water supply, and lower groundwater levels. Water shortages can lead to transition to other agricultural crops. With less water supply and/or lower groundwater levels less irrigation is possible, or extra storage of water is needed.
  - Increase in precipitation in winter can cause damage to certain plants.
  - In case of more rainfall in spring and autumn this may cause problems with the soil preparation, sowing and planting, and harvesting (possibility becomes limited, the risk of fungal infections increases).
  - Extreme precipitation can cause damage to plants, temporary water logging or floods due to limited soil infiltration capacity. Marshy pastures can cause health problems for cattle.
  - Increase in hail, thunderstorms and wind may damage plants.

- Changes in temperature and precipitation affect **emissions of NH_3 and NO_2**. At lower temperatures volatilization of N from manure is lower. With higher rainfall there may be more flushing of N from manure to groundwater or surface water.

- **Changes in radiation** may affect the maximum crop production.

- **Wind and humidity** affect the heat output to the environment and therefore indirectly the water demand and the amount of water stress that plants experience. In addition, the humidity affects the final humidity of crop products.

- **Sea level rise and lower discharge** in summer allows salt water to penetrate further inland. Saltier water affects crop production negatively. The combination of sea level rise and changes in the discharge of rivers can lead to increase of flooding.

3.1.7.3.2 Hazards specific thresholds, recording and tools

The researchers indicate that there are some critical climate thresholds (temperature, moisture) at which a pest or disease can expand, settle, or develop.

3.1.7.4 *Use of climate data*

The researchers use mainly climate data that they download from the website of the national meteorological institute. These are station observations. They do not use a spatial pattern of change since it is hard to process the data. They indicate that the spatial data is smoothed over grid boxes which consists of a larger area than their area of interest. Researchers are not interested in particular metrics or indices, but information on trends or extremes would be useful as it helps them to reduce the computational load.

Previous user requirement inventories indicate that climate data is used in research on changes in production potential, opportunities for other crops/varieties, changes in suitable production sites, ecosystems, chances of extinction/expansion of diseases/weeds, calculating possible coastal erosion/growth, chances of floods (e.g. insurance). In addition, policy focused analyses on risk spread and increase resilience by increasing genetic resources species diversity (interaction ecosystems and agriculture) used climate data as input. Climate data was also required in flexible water level management policy (including adjusting drainage regimes for the salinity gradient, groundwater) and optimization of water retention in river basins, construction of water basins, space for water, dike reinforcement, and to adjust fishing quotas.

3.1.7.4.1 Past climate data

The researchers use historical weather data over the past 30 years to assess climate change impacts on the agricultural sector. The data is obtained from the website of the national meteorological institute.

3.1.7.4.2 Future climate data

The researchers use future climate change scenario data of four scenarios from the national meteorological institute of the Netherlands to assess future climate change impacts on the agricultural sector on a national scale. For European-wide studies the IPCC emission scenarios are used.

3.1.7.4.3 Desirable data characteristics

The researchers indicate that it would be useful if changes in climate events relevant for the agricultural sector would be available. This would support them and reduce their time spent on time series analyses. Ideally they would like to provide a list of criteria and definitions and get the outcomes. For example, a straightforward index is a heat wave which is defined as five days with maximum temperatures higher than 25°C, of which three days with maximum temperatures higher than 30°C [6]. But in the agricultural sector also specific combinations of different variables are relevant, for example moisture and temperature. For pests and diseases wind direction is important. This variable is currently not available in the national climate scenarios. Information about (the timing and frequency) of extremes and variation between years, between seasons, and between days, are also important Variables of interest are soil and water temperature, minimum and maximum temperature, potential evaporation, wind speed and direction, relative humidity, radiation, precipitation, CO_2 concentration, ice, hail, and drought.

3.1.7.4.4 Gaps in current understanding or the tools and information used

Researchers are not used to netcdf format, therefore it is hard to use the output data from climate models directly.

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[6] https://www.knmi.nl/kennis-en-datacentrum/uitleg/hittegolf

3.1.7.4.5 Data resolution

For agricultural research purposes, daily data are useful. To compute the impact of heat waves and storms the daily maxima are important. Spatially, researchers are interested in as scales as fine as possible, since they often want to compute effects for individual farms. However, they also indicate that the higher spatial resolution can give a false impression of precision.

3.1.7.5 *Type of information from PRIMAVERA*

3.1.7.5.1 General feedback about PRIMAVERA

The researchers are interested in the high resolution scenarios and indicate that they could be useful for their research.

The consultant is currently using observations to inform customers about weather impacts, and is at the moment not interested in the high resolution model output. However, in future when the company wants to focus more on future risks it could become interesting.

3.1.7.5.2 Type of products

For farmers, an animation video would be a good way to inform them. To inform farmers about future climate change, it would be useful to couple future impacts of meteorological events to a historical phenomenon. For some higher-educated farmers, a user interface platform where the user can select the events of interest could be helpful.

The researchers are interested in basic tools for analyses (R or Python scripts) that help them to process the data. Personal communication with climate researchers is still important. Workshops are interesting as well, but instruction videos could be more useful to introduce users to start using climate data so that the user can do it at a time and place that suits the user.

3.1.8 **Interview analysis: health**

3.1.8.1 *Introduction*

3.1.8.1.1 Participants characterisation

We interviewed 2 participants from the health sector. The interviewees are researchers working at a national health institute. One researcher focuses on air quality. The other worked in the past on the impact of climate change on disease spread and currently focuses on water quality in cities.

The participants acknowledge climate change and see the need for adaptation of the health sector to climate change. However, they indicate that individuals working in the health sector are generally not implementing climate change adaptation in their work. Some of them focus on the current climate and weather extremes therein.

In addition to the interviews a literature analysis was done to obtain more detailed information on the health sector. In the following sections we will therefore include some relevant results from previous user requirement inventories[7].

3.1.8.2 *Climate change adaptation/management of the impacts of climate/weather*

The researchers mainly focus on health in urban areas. In cities, health agencies implement changes in housing and infrastructure to adapt to climate change. This includes e.g. greener cities and more water in the city.

3.1.8.2.1 Climate change policy

There is increasing interest in future climate change and adaptation to climate change at a political level. The Paris agreement is leading for policy at national health institutes. This means that the health sector has to make the necessary adaptations to be able to adapt to the temperature changes that are stated in the agreement.

3.1.8.2.2 Future perspective

At a political level there is interest in climate change impacts on health until 2040. Infrastructural changes in general have a long-term perspective, with 2020-2030 as time horizon. For future adaptations focusing on air quality, 2030 is the time horizon that is typically used.

3.1.8.3 *Hazards*

3.1.8.3.1 Hazard type and characteristic

The main hazard types in the health sector that the interviewees mention are heat stress, extreme precipitation, reduced water quality, and reduced air quality. The participants also mention that most of these impacts are located in the cities and that their institute therefore focuses on adaptation in cities. The urban heat island effect is an important factor here. High temperatures also impact air quality and the amount of pollen in the air that impact people with respiratory diseases such as asthma. Extreme precipitation can cause overflow of the sewerage in cities.

The following hazards were mentioned (also in previous user inventories):

- **Heat and cold stress**: During heat waves, there is an increase in mortality mainly due to heart and vascular diseases, respiratory distress and dehydration. The most vulnerable groups for these types of diseases are

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[7] Information from inventory user requirements in the Netherlands for health and tourism, Bessembinder et al., 2011 KNMI-TR 317

elderly and young children. Due to the mild temperatures in winter, there will be a decrease in mortality in the winter season.

- **UV stress**: UV radiation may cause skin problems and diseases such as burning, solar allergy, and skin cancer. The amount of UV is determined by the amount of clouds, moisture, and dust in the atmosphere and the amount of ozone. The ozone layer at high altitude in the atmosphere protects the earth's surface from UV radiation. The UV load could change due to changes in the mentioned factors.
- **Air pollution**: There is a complex connection between temperature rise and air pollution. Through accelerated processes at higher temperatures, there could be more days in summer with smog (ozone). However, air pollutants will decompose faster when air humidity is higher and in case of more precipitation (in winter) air pollutants will be washed out of the air.
- **Floods**: Sea level rise and increase of rainfall in winter increase the chance of floods along coasts and rivers. In addition to the immediate danger of flooding there are also indirect health risks such as the mental effects of a disaster and the chance of diseases.
- **Danger in traffic**: The expected increase in rainfall intensity can cause more dangerous situations on roads. At the same time, the number of frost days will decrease, resulting in fewer days with slippery conditions.
- Increase in temperature and change in precipitation, humidity, and radiation can influence the occurrence of **diseases and pests**, sometimes positive, sometimes negative. Fungi often thrive in damp weather. On average milder winters ensure that the development of certain diseases and pests is reduced less (by cold periods) and may lead to the invasion of new diseases and pests (e.g. Ambrosia in the Netherlands). Pests can survive longer due to the higher temperatures. In addition higher groundwater levels due to increased rainfall in winter, increase the risk of certain diseases/pests (especially fungi).
- Due to the higher temperature and change in precipitation, new species can grow in a larger area and or in larger numbers. This applies, among other things, to **vectors** (organisms that transmit diseases or parasites to humans, animals and plants) such as the tick and the tiger mosquito. The chance of spreading of these vectors is also higher due to the higher mobility of man, cattle, and goods. With higher temperatures there are more opportunities for outdoor recreation, and this also enhances the likelihood of contact with vectors.
- A change in air circulation patterns can affect the long distance transport of pollen, e.g. birch **pollen** from Scandinavia. Due to the higher temperatures, the growing season of certain plants can also be extended, which could lead

to, for example, an extension of the hay fever season. Also the number of pollen can increase.

- The rise in temperature and a change in precipitation can reduce the **water quality** in sea, lakes, rivers, waterways change (increase of blue-green algae, botulism, possible concentration of chemicals during droughts, more nutrient spills due to extreme precipitation).
- The risk of disease due to food poisoning increases due to an accelerated decline in **food quality** at higher temperatures. There is also an increased chance of Legionella.

3.1.8.3.2 Hazards specific thresholds, recording and tools

For the impact of heat waves, thresholds that are used in decision making are based on a definition but in reality there is no clear threshold value for heat wave impacts on health. For pathogen spread, threshold values are also on a sliding scale and there is no real threshold value.

3.1.8.4 *Use of climate data*

The health researchers do not use specific climate data in their work. They acknowledge that the climate is warming, but do not use exact numbers for future scenarios. The only information that they use is that ‘the climate is warming’ and the so-called ‘urban heat island effect’. They notice that information about climate extremes is especially interesting, for example the number of heat waves in the future. The researchers indicate that for adaptation planning it is not necessary to know the exact numbers, and only the general trend is enough. One researcher indicates that for the spread of vectors and diseases he used some climate data (moisture, temperature, solar radiation) that were available via the website from the national weather institute, but does not remember exactly what data.

In previous user inventories, health researchers mentioned that they use climate data to do research on the spread of existing, but still rare diseases, to obtain information about potential new diseases and about effects of heat. This information can then be used to set up and/or modify warning systems for e.g. allergies, air quality, flood hazards, and water quality. In addition, there is a growing attention for the direct and indirect effects (e.g. mental effects and fungi) of floods on health in emergency care. Also, the possible adjustment of existing standards for the construction of houses, offices, and office care facilities (with sufficient heat cooling ability) and strategic decisions on infrastructure for health care and options to reduce health problems (e.g. more green spaces to reduce heat stress) includes the use of climate data.

3.1.8.4.1 Past climate data

The air quality researcher uses observations from the national meteorological institute as input for an air quality model. Water quality research is focused on observations of the water, but does not include climate data since it is focused on the current situation and not on changes over time.

3.1.8.4.2 Future climate data

Both researchers mention that currently they do not use any climate data for the future.

3.1.8.4.3 Desirable data characteristics

Air quality research needs data of temperature, precipitation, and wind. One researcher notices that wind direction is difficult to analyse and it is better to have pre-processed data for wind.

3.1.8.4.4 Gaps in current understanding or in tools and information used

The researchers do not feel that there is a gap in their understanding. The water quality researcher does not feel the need for detailed future climate information. The air quality researcher addresses that this is currently changing in his field and thinks that more and more people in his field will be focusing on the impact of (future) climate change on air quality.

3.1.8.4.5 Data resolution

The air quality model uses 6-hourly data on high spatial resolution. Typically air quality predictions are currently made at 1x1 kilometre.

3.1.8.5 *Type of information from PRIMAVERA*

3.1.8.5.1 General feedback about PRIMAVERA

The air quality researcher thinks that the resolution of global climate models increases is an interesting development. Since air quality models use a grid of typically 1x1 kilometre, high resolution climate data would be more suitable as input than medium resolution data. Both researchers notice the importance to know the uncertainty that is associated with future climate projections.

3.1.8.5.2 Type of products

In general the health sector wants information and not climate model data. An exception are air quality models that need bias-corrected climate data as input. The researchers prefer to read information in technical reports. Visuals that show changes in relevant climate events might be interesting for them to inform the general public and individual health workers about future changes. Researchers are also interested to use visuals to show the relevancy of adaptation in the health sector to climate change to policy makers in their field.

3.2 Cross-sectoral analysis

A comparative analysis across sectors allows us to identify general areas of agreement and disagreement. These similarities and differences are not always most dependent on the sector, with other factors (such as the type of role and level of experience with weather/climate) being more prominent.

3.2.1 Levels of knowledge / experience

Across sectors, there is a wide range of knowledge of weather and climate change, and of experience of using weather and climate change information to the user's/sector's advantage. Probably the most "advanced" sectors are insurance and energy. In terms of weather/climate change knowledge, the academics/researchers were generally the best informed. In terms of experience, this was rather more dependent on individuals and the nature of their roles (e.g. some stated that they were the "resident expert" about weather and/or climate change within their organisation, and therefore it was expected that they would be knowledgeable).

3.2.2 Attitudes to climate change

Among those interviewed, there was widespread acknowledgement of climate change and its potential effects. That said, there was some feeling among interviewees in roles involving onward stakeholder/customer contact (e.g. consultancy, sector-focused umbrella organisations) that their onward contacts might not share that view.

There was definitely variation in how sectors were responding to the challenge of climate change, but there did not seem to be a particular pattern to this. Barriers to and enablers for action were occasionally discussed, e.g. obligations arising from legislation, or barriers arising from a slow response of sectoral policies to the prevailing science. There was some dependence on the perceived size of the problem – for example, finding a solution to an impact at a single location on one type of infrastructure being more tractable than finding a solution to an impact on human health, which could be geographically widespread.

3.2.3 Hazards

There was wide variation in the most interesting / impactful hazards per sector. Rainfall and rainfall-related flooding, and high winds, were the ones that were most commonly rated as particularly interesting / impactful (as described in the survey results). High temperatures and coastal flooding were also a recurring theme across sectors.

There was no consensus on what aspects of hazards were most damaging (intensity, scale, duration, timing...); this is very specific to the hazard and the sector concerned. Some interviewees however mentioned that the combined and cumulative effect of different hazards was the aspect that mattered the most.

3.2.4 Time horizons

Almost all participants – with the exception of the two from the health sector – used past (historical) climate data; however, there was variation in how far back in time people considered when using these data.

For some stakeholders the interest was to have data as far back in the past as possible to understand if a similar weather event had happened before and how the system behaved, e.g. the response of the system after a catastrophe – that is particularly interesting for the insurance sector, or the influence of the extreme floods or droughts on the agricultural system, or on a particular watershed – which are the questions agricultural researchers and water managers want to address. Some people in the transport sector also used past data for similar reasons. Long timeseries of past data can also help the energy managers determine a typical energy day, in terms of energy demand and generation. Some researchers use past climate data to train their models; in these cases, a shorter period usually suffices.

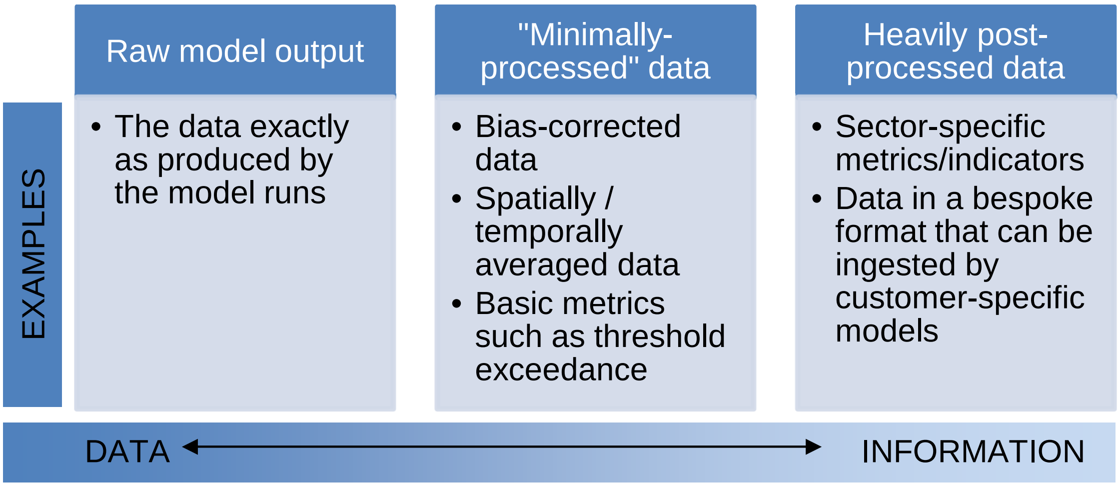
The future time horizon of interest depends on the sector, e.g. farmers plan in advance, for long-term investments; the energy and transport system planners are concerned with the long term time scale for decisions about the commissioning of long-lived assets, e.g. the design of new plants (energy) or bridges (transport); the insurance sector is interested in the next 10 year time horizon. However, less than by the sector, the future time horizon of consideration is rather determined by the nature of the interviewees' area of work. Those with operational responsibilities tended to focus more on the shorter term, with the longer term being more relevant for those involved in strategic/planning roles. In general, only those working in research were accustomed to working with different types of data which are pertinent to different timescales (historical, current and future), and the different skills and knowledge needed to work with these different data types.

There were also comments referring to the importance of interannual variability, with some respondents noting that what happened from year to year (and how it was managed) being just as important as what might happen in the longer term. The insurance sector was a notable example, with the major interest there being on current and near-future events and not so much on the longer term.

3.2.5 "Data", or "information"?

Most sectors seemed to favour information over data. The most commonly-cited reason for working with information rather than data was a lack of expertise with respect to the data, while the lack of computational capacity was also cited. The people who most often worked with data rather than information were those working in research. These participants mainly prefer to tailor data specifically to their needs – perhaps even running climate models themselves – rather than to use ready-made datasets.

In those cases where participants were interested in receiving raw data, it was not always clarified what they meant by this term, e.g. whether they could handle data that was not bias corrected. In reality, there is a spectrum spanning the terms “data” and “information”, for example:



For the health, agriculture and water sector information about the future climate trend was very important. Conversely, participants from the insurance and energy sectors were interested in information about future hazards and extremes data. Extremes data can help set new regulations about asset design or help (re)assess weather and climate risk, update insurance pricing and decisions about who to insure. The sectoral variation here is possibly linked to the general level of weather and climate change knowledge and/or experience (see Section 3.2.1); this would seem to be borne out by the more mixed response from transport, with the more experienced respondents discussing hazards and the less experienced focusing more on the higher-level messages.

3.2.6 Resolution

The concepts of higher spatial and temporal resolution were favourably received. The more cautious reception tended to correspond to the more experienced users, who are conscious of the fact that “higher resolution” does not automatically mean “better”. Some participants, particularly researchers, were also aware that higher resolution data would demand more computational capacity that was not always available for them. Interestingly, some participants expressed clear distinction between their need for spatial vs. temporal resolution, one such example comes from the energy system researchers and planners who expressed strong demand for better temporal resolution (half and quarter hourly data), but not a particular need for space resolution. Some more detailed comments on resolution may be found in Sections 3.3.1.2 and 3.3.1.3 below.

3.2.7 Products

Certain requirements for products and information from PRIMAVERA recurred across sectors and types of user, and are presented below, using the four categories that were explicitly probed in the survey and interviews. Some of this information will be useful when planning future user engagement within the project (e.g. further fact sheets; other UIP content).

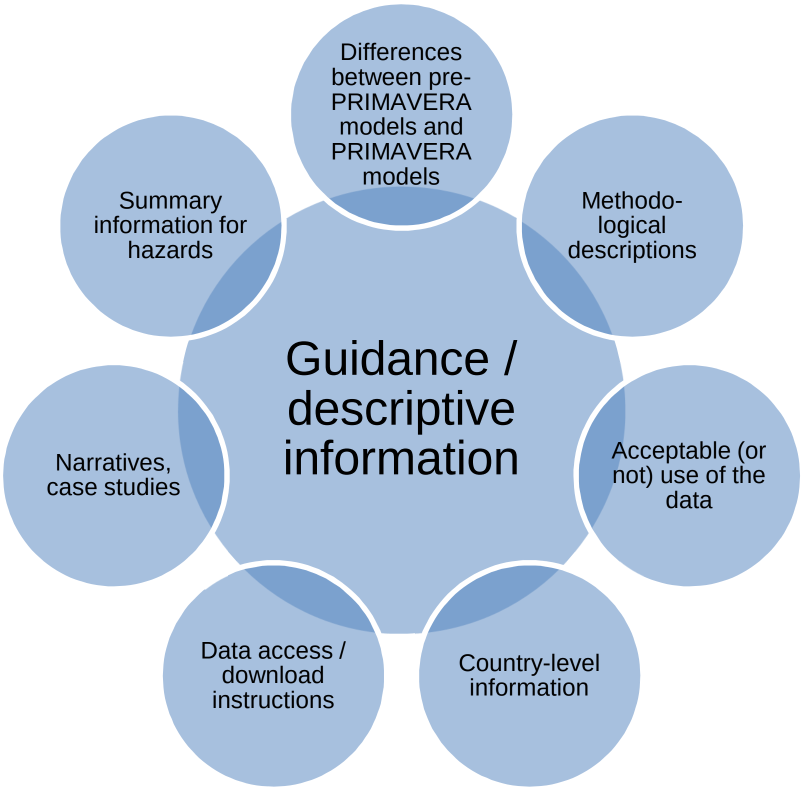


Figure 15: Recurring themes in interviewees' preferences for guidance and descriptive information.

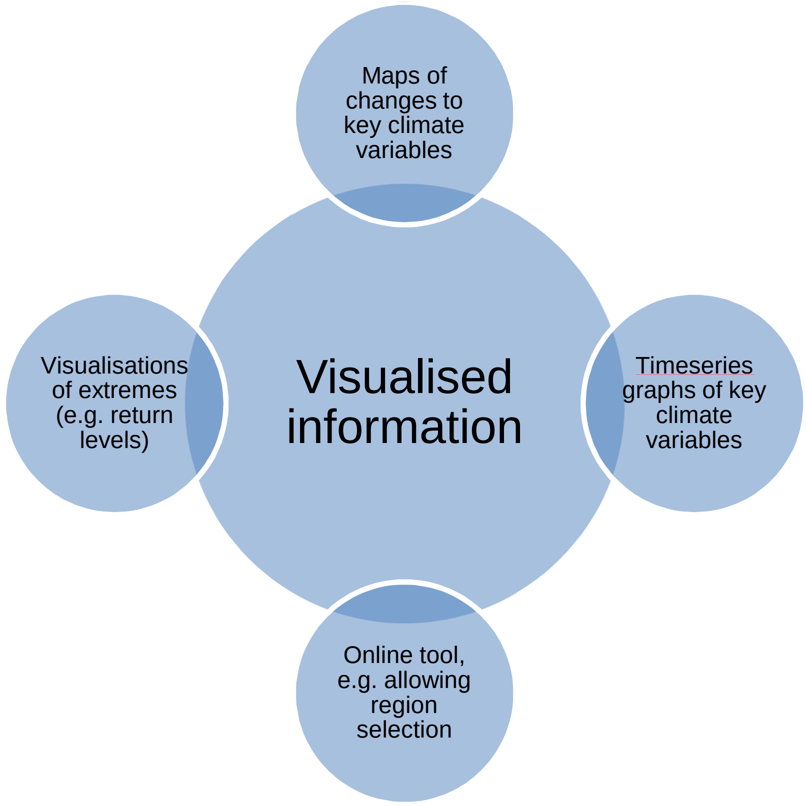


Figure 16: Recurring themes in interviewees' preferences for visualised information.

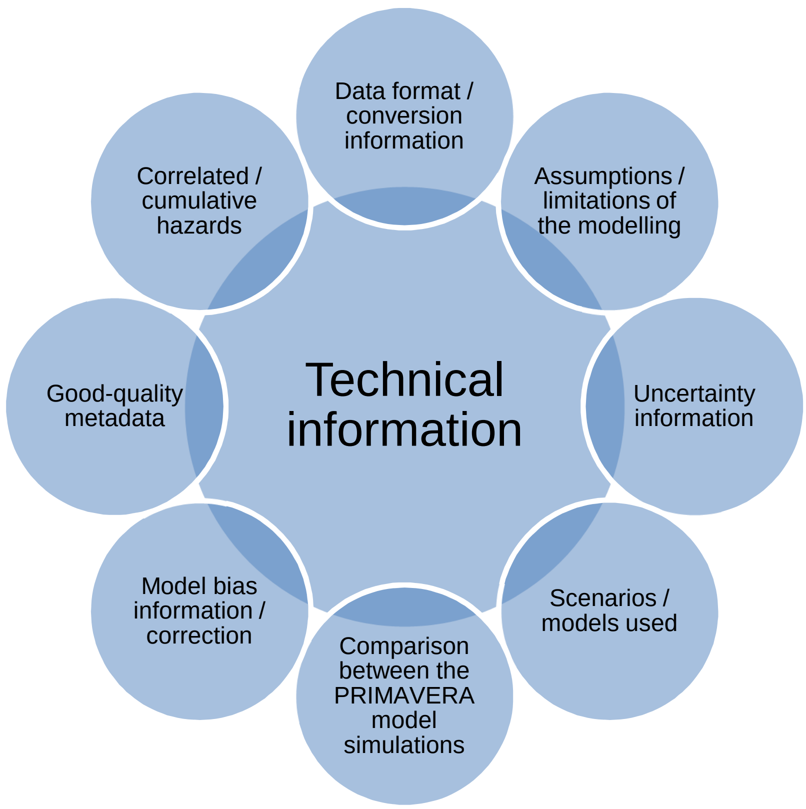


Figure 17: Recurring themes in interviewees' preferences for technical information.

Figure 18: Recurring themes in interviewees' preferences for training.

3.3 Feasibility of user requirements

3.3.1 User requirements and project limitations

In addition to providing a valuable insight into user needs and requirements, as well as their expectations from PRIMAVERA, the survey and interviews also revealed the following limitations and challenges in addressing the user needs. These are listed below, according to various features of the requirements.

3.3.1.1 *Type of hazard*

- Coastal hazards: Some general aspects of coastal hazards (i.e. storm surges, extreme wave heights) have the potential to be addressed using the PRIMAVERA runs, such as the increased risk of certain events due to sea level rise. Nonetheless, if the interest is on certain coastal energy infrastructure, the spatial resolution of the simulations (typically 25km) does not provide a detailed representation of the coastal features necessary to address the associated risks to specific infrastructure.
- Ice formation: The PRIMAVERA runs might help identify regions where an increase in the frequency of temperatures below freezing is expected, but the spatial scale of such areas is also of the order of 25km by 25km (or even larger), so the information will not be suitable, for instance, to identify specific detailed locations for installing new turbines.

- Lightning: Electrical discharges were identified as a focus of interest due to the risk they pose to wind turbines and electrical substations. Lightning is a process that occurs within thunderstorms, at scales much smaller than the model's resolution and therefore it is not a magnitude that is directly computed by the model. Nonetheless, some information can be provided about regional changes in the 'convective energy' that is available to storms, since this is directly linked to the severity of the systems and the likelihood of producing lightning. This information would also be limited by the 25km horizontal resolution, and additionally, also limited in its accuracy by the vertical resolution of the models. Users identified very precise products such as the number of flashes per square km, which the models are clearly not able to produce.
- Convective precipitation: Several users identified a need for information about convective precipitation. Since convection permitting models (those that do not require a parameterization and can explicitly resolve convective processes) are of at least 4km resolution, the PRIMAVERA runs will not be able to address this requirement.
- Flooding: Although flooding is clearly a major topic of concern across sectors, the PRIMAVERA runs do not simulate flooding explicitly. This would require further models to be run offline, driven by PRIMAVERA data. This is not within the scope of the project. It could be possible to explore surface water flooding by using heavy rainfall as a proxy, but it remains to be seen whether the PRIMAVERA models will simulate this kind of rainfall well enough (see preceding point).

3.3.1.2 *Temporal resolution*

Some of the users identified events at very high temporal resolution as being of interest. A concrete example is the maximum 10-minute wind speed. It is not feasible to provide this information, mainly since this would mean storing a huge amount of data (even storing data at the hourly level is quite restrictive for these high-resolution models), but also because the models are not intended to represent the type of physical processes that cause such high frequency perturbations, such as those related to turbulence. More frequently, users expressed an interest in half- and quarter-hourly data.

Stream 1 simulations should provide some sub-daily data (3- or 6-hourly), and Stream 2 should provide the facility for some data at even higher temporal resolution to be stored, though for limited time periods.

3.3.1.3 *Spatial resolution*

A portion of the users expressed a need for very high spatial resolution, such as global scale 3km data and beyond. The typical resolution of the Stream 1

PRIMAVERA runs is 25km and even the Stream 2 'Frontier' runs will not have resolutions much finer than 5km, and are therefore unable to comply with those requirements.

However, there was interest (sometimes tentatively) in data at the 5-25km spatial scale from some sectors. It will be necessary to explore how to maximise the usefulness of this information to the user – for example, highlighting the increased benefits of *higher* spatial resolution in terms of the statistical representation of some hazards, rather than focusing too heavily on exactly *what* that specific resolution is.

3.3.1.4 *Data capabilities*

Many users are interested in using PRIMAVERA data for in-house impact models rather than relying on pre-produced figures or reports produced by PRIMAVERA. This, however, raises several important issues:

- To what extent is the PRIMAVERA consortium prepared to share the quantitative 'raw' GCM output with stakeholder partners?
- How can this best be facilitated?

It is particularly noted that the user groups have reported a range of data processing capabilities within their organisations. Their requirement can therefore range from a desire to access the true 'raw' high-frequency GCM data (3-6 hourly gridded surface fields) to a recognition that pre-processed and highly aggregated data is needed (e.g. spatio-temporally averaged data such as monthly means over particular spatial domains).

It is our opinion that some of these misconceptions about what type of information can be gained from the next generation of climate models could be addressed by workshops, webinars or other types of training material; explaining the idea behind climate modelling and the differences between GCMs and regional climate models.

3.3.2 Fulfilling user requirements

Some of the user needs could be translated into demonstration case studies for the targeted use of the PRIMAVERA model output, some examples are:

1. Intercomparison of PRIMAVERA with pre-PRIMAVERA models, such as CMIP5 and CORDEX for some of the variables, such as surface air temperature, rainfall and wind.
2. Representation of current variability and future projections in GCMs. One example is spatial correlation of high/low wind events across Europe or a certain region (at hourly or daily timescales).
3. Climate change information for planning. Finding 'consistent' climate signals and understanding the impact of future climate projections on different sectors.

4. Extreme events, including extreme event clusters (i.e. extreme events that occur more than once in a relatively short period), changes in frequency/return-period as a function of global mean temperature.
5. Compound events, such as high-wind/rainfall or high-tide/storms. Concerns include infrastructure damage or in the case of low-temperature/low-wind, a challenge for energy managers to address the increased energy demand from the cold period with reduced wind power generation.
6. Use of ‘raw surface impact data’ for in-house models. High spatio-temporal frequency needed to feed into quantitative models to understand the impact of different circumstances on the certain systems. In this case ‘raw data’ may include some post-processing in practice (e.g. interpolation onto standardised grids or vertical levels).
7. Hydrological models for river flow and temperature. Monthly and daily timeseries could help avoid downscaling.

Besides, some “wishlist” items in Section 3.2.7 above are easier to provide than others. Broadly, the items fall into the following categories:

1. Background / supporting materials (scenarios used; information about uncertainties; assumptions and limitations of the modelling; training resources...)
2. Data and related materials (metadata; formats and conversion; access/download; bias correction...)
3. Processed materials (maps and graphs showing analysis of PRIMAVERA model output; country-level information; fact sheets, narratives and case studies...)

It should be possible to provide many of the materials in each category, or at least links to existing resources for some of them. The provision of data is an open question (as per Section 3.3.1.4 above). Further user engagement will be needed to understand exactly what processed materials could be useful to users in category 3.

4 Issues encountered to date

4.1 Stream 1 delays

WP11 (and also WP10) activities have been designed to support the incorporation of user feedback into the design of PRIMAVERA’s Stream 2 experiments. However, the user survey and interview responses do not provide information that is sufficiently detailed as to inform the Stream 2 design. This can only be gathered from highly bespoke user engagement, which is yet to come.

At the time of writing, delays to the Stream 1 simulations are making it difficult to progress on this subject, as it is logical to present multi-model Stream 1 results as an entry point for users. With the Stream 1 delays, we have limited capacity to demonstrate possible derived products/visualisations etc based on Stream 1 data, making it difficult to gather focused user feedback on such material. Using other high-resolution model data is an option to address this (this approach has been taken to some extent), but is not desirable for the bespoke engagement as it does not fit with the anticipated approach of being able to use Stream 1 to inform Stream 2.

There is also a risk that the design of Stream 2 could be quite different from what was originally anticipated. Given that the ability to influence Stream 2 has been used as a “hook” in engaging users to date, changes to this could risk alienating users and negating the user engagement work carried out so far.

Still, we managed to identify some of the user requirement aspects that could inform Stream 2:

Regarding the temporal scope of the simulations, there was a strong focus amongst energy sector users for ‘present climate’ runs over the future climate projections. The participants stressed the value and need to have a better representation of current and very near future (1-20 years) climate conditions that would allow them to robustly characterize extreme events and their return periods. There was, however, also a recognised need for climate projections (often connected with the design of ‘assets’ or infrastructure). Changes in the ‘recurrence’ of certain extreme events under future climate were also identified as a topic of interest. Overall, this suggests careful thought should be given to the relative prioritization of ‘present day’ vs ‘future projections’ - a larger ensemble of historical runs and less focus on the future projections may be more useful for many users.

With respect to resolution, increased output resolution (compared to, say, CMIP5), was welcomed with some participants expressing the need for very high spatial resolutions (even unachievable for a GCM). Some users – particularly in the energy sector – were, however, particularly interested in high temporal resolutions. In particular, sub-hourly data for wind and solar radiance was a common request with global coverage. This point is particularly relevant since for the Stream 1 runs, some of these variables were stored at most at hourly resolution, and over a limited European domain. Clearly PRIMAVERA models will fail to provide useful information at some spatio-temporal scales – e.g., reanalyses are typically only useful for assessing the patterns of Western European wind power variability at scales greater than ~200-300km / 3-6h (e.g., Cannon et al, 2015). It would therefore be useful to determine the expected information content (i.e. effective resolution of PRIMAVERA output) in both time and space for surface variables such as wind, solar, precipitation and temperature to inform the list of output diagnostics from Stream 2. It is also important to recognise that some issues remain concerning communicating an ‘understanding’ of PRIMAVERA’s primary advantages over other GCM studies to many users – i.e. increased resolution for representing physical processes rather than simply providing better localised surface data.

4.2 Geographic bias in user engagement

A known issue (and one which is not unique to PRIMAVERA) is how to engage better with the user community in Eastern Europe. While efforts were certainly made to engage with this group (including contact in native languages where possible), there were few responses, and those who were interested were sometimes limited by other issues (e.g. civil servants in one country could not obtain a permit to take part in the interview during the government's transition period after the elections).

Many of those working in WP11 are also (or have colleagues who are) working on other projects with similar user engagement objectives. Hence, there is significant scope for seeking solutions to this issue collaboratively across projects.

5 Next steps

A wealth of information has been collected in the survey and interviews, and provides plenty of opportunities for onward engagement with users.

Our next steps in WP11 are:

- To present, via a **general webinar** / virtual meeting, an overview of the findings from the survey and interviews, with an opportunity for questions and discussion at the end of the webinar
- To present a series of **sector-focused webinars** / virtual meetings, which will provide a more detailed view of responses within a sector and give new participants the chance to get involved in PRIMAVERA. These webinars could also address some of the more general themes that have arisen, e.g. the perception of "too much information" and not knowing what to do with it
- (With WP10) To engage "**sector champions**" – particularly engaged users who can act as an entry point into a given sector (since other users are more likely to engage with PRIMAVERA if they hear about its benefits from colleagues within their field)
- To continue engaging as much as possible with users via our mailing list (primavera_updates@bsc.es), new Twitter feed (@PRIMAVERA_H2020) and other channels (e.g. conferences)

6 Lessons learnt

A key lesson learnt concerns the **time involved** in preparing and executing user engagement work:

Preparatory activities include drafting contact approaches (e.g. initial mailshots to stakeholders, which must be carefully worded to optimise the level of response), and background administrative activities such as ensuring compliance with current EU (and country-level) legislation about data protection and privacy – specifically regarding the survey and the audio recording of some of the interviews. The latter has been especially time-consuming and it is likely that the coming introduction of the GDPR (http://www.eugdpr.org/) will require further attention to be paid to this topic in future.

Executing user engagement consumes both effort (it takes a lot of time to analyse responses to the interviews in particular) and elapsed time (users are busy people and need to find time in their schedules to accommodate interview slots). Should further interviews be necessary, outsourcing some or all of that activity is a possibility, subject to available funds.

Motivating user interest in the project and *encouraging engagement* is challenging since we compete with a plethora of other information which users are regularly receiving. In addition, many other climate data and services projects are conducting user engagement activities. Besides the importance to coordinate our efforts with other activities and projects (see Section 7), we should also aim to provide attractive and innovative approach and content, balancing between too little and too much information. In this respect, we are approaching PRIMAVERA stakeholders using different communication channels, such as the mailing list, personal communication in the conferences and other events, social media. On the User Interface Platform (D11.2), we also present a summary of the project, along with user relevant content using modern communication approaches such as the storymaps and the project factsheets.

7 Links built

Building links is the essence of WP11 – whether internally to the project, internally to the research community at large, or externally with users.

Internal project links include:

- The close links between WP11 and WP10 (for example, the survey and interview outcomes have contributed to the work of WP10 and in particular the D10.1 deliverable)
- The privacy / data protection / consent process has developed the work that was started in WP7 (e.g. updating the interview consent form)

Internal research community links include:

- Promotion and publicising of PRIMAVERA at numerous external conferences, including:
    - Copernicus C3S General Assembly, https://climate.copernicus.eu/events/c3s-general-assembly
    - EGU 2017, http://www.egu2017.eu
    - ECCA 2017, http://ecca2017.eu/conference
    - Royal Met Soc annual conference 2017, https://www.rmets.org/annual2017

- o EMS 2017, http://www.ems2017.eu

Note that some of these conferences also involve the user community as well as the science community. The conferences also provided an opportunity to link with other H2020 projects with the similar research focus, find synergies and exchange our experience in user engagement activities. It is particularly important to be aware of and coordinate with other projects' user surveys and other participatory activities related to the use of climate data and services, so to minimize participants' fatigue.

Strong *external* links have been built with some of the users. In particular, a few energy sector users expressed interest for further collaboration and were contacted for more focused interaction with the PRIMAVERA scientists. There has also been interest from the insurance community. It is anticipated that these links will further strengthen and increase in number as WP11 continues.

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Appendix A: interview questions for “general users”

Thank you for agreeing to take part in an interview for the PRIMAVERA project. This interview is being recorded in accordance with the consent form which you signed recently.

We will spend the next hour or so asking you a series of questions to develop the series of questions we asked in the survey a few months ago. We aim to keep our questions fairly open to avoid influencing your responses, but if you are not sure what we are asking you, please ask for clarification.

Finally please note that PRIMAVERA is focused on Europe and hence we would ask you to focus your responses primarily on Europe where possible.

Attitudes to climate change

The first few questions are about your organisation’s attitudes to climate change.

1. What is the attitude of your wider organisation towards future climate change?

    1.1. [*OPTIONAL] Do you feel that your organisation/sector acknowledges climate change?*

2. Do you think that, in the future, climate/weather hazards could become more important for your work/organisation/sector?

    2.1. [OPTIONAL] Do you feel that your organisation/sector needs to adapt to climate change?

    2.3. [OPTIONAL] What kinds of measures are required for your organisation/sector to adapt to climate change?

    2.2. [OPTIONAL] Do you think your organisation has sufficient access to information about future climate change?

    2.4. [OPTIONAL] Do global and European political decisions, recommendations and commitments, such as Paris agreement or EU2030 Framework for Climate and Energy influence the work of your organisation/ sector?

3. When managing weather and/or climate-related issues, how far into the future do you consider?

Management of weather/climate hazards

The next few questions are about your organisation's management of weather and climate hazards.

4. How are the impacts of climate/weather managed in your organisation?

5. [Remind them of their answers to Survey Q5-7] Please can you expand on why you rated the hazards as you did?

6. Which aspects of these hazards brought most damage?

   6.1*. [OPTIONAL] Are there any specific past weather events which relate to how you rated particular hazards?*

   6.2. [OPTIONAL] Do you record the historical impacts of weather and climate on your organisation? [If so, how, and where (internally, externally)?] Are the impact data available publicly?

   6.3. Are there any climate-related critical thresholds that are of interest for your organisation?

7. Which weather and climate hazard datasets and tools do you use in managing weather and/or climate impacts? Why do you use these?

8. Do you focus more on using climate data [that is, raw data from the models] or climate information [that is, processed data, or products derived from climate data]?

   - If "climate information", Q8.1
   - If "climate data", Q8.2

   8.1 Why don't you use climate data?

   8.2 Do you use any particular metrics, indices or indicators in your weather management / climate planning?

9. [Remind them of their answers to Survey Q11&12] Do you perceive any gaps in your understanding or in the tools and information you currently use?

Use of climate information

The next few questions are about your organisation's use of climate data and information.

10. Does your organisation use historical climate/weather data or information (that is, information or data about past weather/climate)?
    - If yes, Q11
    - If no, Q14

11. What data or information do you use and from where do you obtain it?

12. What do you use it for?

13. Which time period in the past is of most interest to your organisation?

14. [Remind them of their answers to survey Q8] Does your organisation use data or information about the future climate?
    - If yes, Q15
    - If no, Q18 OPTIONAL or Q19

15. What data or information do you use and from where do you obtain it?

16. What do you use it for?

17. Which time period in the future is of most interest to your organisation?

18. [OPTIONAL – only use for respondents saying “yes” to Q8 and/or Q10 and/or Q14] [Remind them of their answers to survey Q9] Thinking back to your answers about the past and future climate information that you use, why do you use this particular information instead of information from other sources)?

What PRIMAVERA could provide

The next few questions are focused specifically on the current project, PRIMAVERA.

Types of information

PRIMAVERA will provide derived products, guidance, visualisations, training, and sector-focused information. Earlier, I asked about how you manage weather and climate issues at present, and which tools and data you use to do that. Thinking about your answers to those questions, what other types of weather/climate information products and support would you find useful from PRIMAVERA? There are four categories of information I would like you to consider. [Remind them of their answers to survey Q14]

19. What guidance and descriptive information would be useful? In what format?

20. What data and technical (specialised) information would be useful? In what format?

21. What visualized information would be useful? In what format?

22. What training materials and activities would be useful? In what format?

Temporal/spatial scales; lead time of information

23. [Remind them of their answers to survey Q11 & Q13] One of PRIMAVERA's main aims is to provide climate information at a finer spatial scale through use of higher resolution climate models. By finer scale I mean at a resolution of typically 25km. This higher spatial resolution can better simulate certain aspects of climate and climate change.
    - In your survey answers you suggested that information at this kind of spatial resolution [would/might be/would not] be useful to you. Please can you tell me more about the reasoning behind your answer?

24. [OPTIONAL] [Remind them of their answers to survey Q11] When you're using or thinking about climate data or information in your work, what spatial scale would you usually focus on?

25. When you're using or thinking about climate data or information in your work, how granular is the time resolution of the data that you would usually want to use?

Climate change opportunities [optional]

The next two questions are about opportunities from climate change.

26. [OPTIONAL] Do you think there could be any positive impacts/opportunities related to climate change for your organisation?

27. [OPTIONAL] Thinking about how your organisation manages weather and climate now, do you have any ideas how you might capitalise on those potential opportunities?

Closing

Some final questions before I conclude the interview.

28. Is there any other information which you feel would be useful to pass on to me in the context of this interview?

29. Should I invite someone else from your company to participate in an interview? Please give me the contact details of anyone who might be suitable.

Appendix B: interview questions for "consultants"

Thank you for agreeing to take part in an interview for the PRIMAVERA project. This interview is being recorded in accordance with the consent form which you signed recently.

We will spend the next hour or so asking you a series of questions to develop the series of questions we asked in the survey a few months ago. We aim to keep our questions fairly open to avoid influencing your responses, but if you are not sure what we are asking you, please ask for clarification.

From your survey responses we note that you are a consultant. When answering the questions, we would like you to answer with your client organisations, and your work for them, in mind. We acknowledge that some of the questions may have diverse answers depending on variation across your client base; in such cases, we would like you to comment both on general principles, and on any notable exceptions. We also accept that client confidentiality may limit the extent of your answers; if that is the case then please simply keep the client organisation names confidential and refer to them by their sector (e.g. "one of my clients in the energy sector").

Finally please note that PRIMAVERA is focused on Europe and hence we would ask you to focus your responses primarily on Europe where possible.

Attitudes to climate change

The first few questions are about the attitudes to climate change of your client organisations.

1. What is the attitude of your clients towards future climate change?

   1.2. [OPTIONAL] Do you feel that your clients acknowledge climate change?

2. Do you think that, in the future, climate/weather hazards could become more important for your clients?
   2.1. *[OPTIONAL] Do you feel that your clients need to adapt to climate change?*

   2.3. *[OPTIONAL] What kinds of measures are required for your clients to adapt to climate change?*

   2.2. *[OPTIONAL] Do you think your clients have sufficient access to information about future climate change?*

2.4. *[OPTIONAL] Do global and European political decisions, recommendations and commitments, such as Paris agreement or EU2030 Framework for Climate and Energy influence the work of your clients?*

3. When managing weather and/or climate-related issues, how far into the future do your clients typically consider?

Management of weather/climate hazards

The next few questions are about the management of weather and climate hazards in your client organisations.

4. How are the impacts of climate/weather managed in your client organisations?

5. [Remind them of their answers to Survey Q5-7] Please can you expand on why you rated the hazards as you did?

6. Which aspects of these hazards brought most damage to your clients?
6.1. *[OPTIONAL] Are there any specific past weather events which relate to how you rated particular hazards?*

6.2. *[OPTIONAL] Are the historical impacts of weather and climate recorded formally within your client organisations? [If so, how, and where (internally, externally)?] Are the impact data available publicly?*

6.3. Are there any climate-related critical thresholds that are of interest for your clients?

7. Which weather and climate hazard datasets and tools do you use when conducting consultancy work for your clients? Why do you use these?

8. Do you focus more on using climate data [that is, raw data from the models] or climate information [that is, processed data, or products derived from climate data] in consultancy work?

   - If “climate information”, Q8.1
   - If “climate data”, Q8.2

   8.1 Why don’t you use climate data?

8.2 Do you use any particular metrics, indices or indicators in your weather management / climate planning work for clients?

9. [Remind them of their answers to Survey Q11&12] Do you perceive any gaps in your understanding or in the tools and information you currently use for your consultancy work?

Use of climate information

The next few questions are about the use of climate data and information in consultancy work for your client organisations*.*

10. In your consultancy work, do you use historical climate/weather data or information (that is, information or data about past weather/climate)?
    - If yes, Q11
    - If no, Q14

11. What data or information do you use and from where do you obtain it?

12. What do you use it for?

13. Which time period in the past is of most interest?

14. [Remind them of their answers to survey Q8] In your consultancy work, do you use data or information about the future climate?
    - If yes, Q15
    - If no, Q18 OPTIONAL or Q19

15. What data or information do you use and from where do you obtain it?

16. What do you use it for?

17. Which time period in the future is of most interest?

18. *[OPTIONAL – only use for respondents saying “yes” to Q8 and/orQ10 and/or Q14] [Remind them of their answers to survey Q9] Thinking back to your answers about the past and future climate information that you use in your consultancy work, can you comment on why this particular information is used, instead of information from other sources)?*

What PRIMAVERA could provide

The next few questions are focused specifically on the current project, PRIMAVERA.

Types of information

PRIMAVERA will provide access to derived products, guidance, visualisations, training, and sector-focused information. Earlier, I asked about how your clients manage weather and climate issues at present, and which tools and data you use in your consultancy work, to support them with that. Thinking about your answers to those questions, what other types of weather/climate information products and support do you think would be useful from PRIMAVERA? There are four categories of information I would like you to consider. [Remind them of their answers to survey Q14]

19. What guidance and descriptive information would be useful? In what format?

20. What data and technical (specialised) information would be useful? In what format?

21. What visualized information would be useful? In what format?

22. What training materials and activities would be useful? In what format?

Temporal/spatial scales; lead time of information

23. [Remind them of their answers to survey Q11 & Q13] One of PRIMAVERA's main aims is to provide climate information at a finer spatial scale through use of higher resolution climate models. By finer scale I mean at a resolution of typically 25km. This higher spatial resolution can better simulate certain aspects of climate and climate change.
    - In your survey answers you suggested that information at this kind of spatial resolution [would/might be/would not] be useful to you or your clients. Please can you tell me more about the reasoning behind your answer?

24. [OPTIONAL] [Remind them of their answers to survey Q11] When you're using or thinking about climate data or information in your consultancy work, what spatial scale would you usually focus on?

25. When you're using or thinking about climate data or information in your consultancy work, how granular is the time resolution of the data that you would usually want to use

Climate change opportunities [optional]

The next two questions are about opportunities from climate change.

26. *[OPTIONAL] Do you think there could be any positive impacts/opportunities related to climate change for your organisation or your clients?*

27. *[OPTIONAL] Thinking about how your work helps your clients to manage weather and climate now, do you have any ideas how they might capitalise on those potential opportunities?*

Closing

Some final questions before I conclude the interview.

28. Is there any other information which you feel would be useful to pass on to me in the context of this interview?

29. Should I invite someone else from your organisation to participate in an interview? Please give me the contact details of anyone who might be suitable.

Appendix C: interview questions for "academics"

Thank you for agreeing to take part in an interview for the PRIMAVERA project. This interview is being recorded in accordance with the consent form which you signed recently.

We will spend the next hour or so asking you a series of questions to develop the series of questions we asked in the survey a few months ago. We aim to keep our questions fairly open to avoid influencing your responses, but if you are not sure what we are asking you, please ask for clarification.

From your survey responses we note that your research is focused mainly in the [*include sector here*] sector. When answering the questions, we would like you to answer with this sector in mind. We acknowledge that some of the questions may have diverse answers depending on variation within the sector; in such cases, we would like you to comment both on general principles, and on any notable exceptions.

Finally please note that PRIMAVERA is focused on Europe and hence we would ask you to focus your responses primarily on Europe where possible.

Attitudes to climate change

The first few questions are about the attitudes to climate change **of the sector in which your research is focused.**

1. What is the attitude of the sector towards future climate change?

   1.1. [OPTIONAL] Do you feel that the sector acknowledges climate change?

2. Do you think that, in the future, climate/weather hazards could become more important for the sector?
   2.1. *[OPTIONAL] Do you feel that the sector needs to adapt to climate change?*

   2.3. *[OPTIONAL] What kinds of measures are required for the sector to adapt to climate change?*

   2.2. *[OPTIONAL] Do you think the sector has sufficient access to information about future climate change?*

2.4. *[OPTIONAL] Do global and European political decisions, recommendations and commitments, such as Paris agreement or EU2030 Framework for Climate and Energy influence the work of the sector?*

3. When managing weather and/or climate-related issues, how far into the future does the sector typically consider?

Management of weather/climate hazards

The next few questions are about the management of weather and climate hazards **in the sector where your research is focused.**

4. How are the impacts of climate/weather managed in the sector?

5. [Remind them of their answers to Survey Q5-7] Please can you expand on why you rated the hazards as you did?

6. Which aspects of these hazards brought most damage to the sector?
6.1. *[OPTIONAL] Are there any specific past weather events which relate to how you rated particular hazards?*

6.2*. [OPTIONAL] Are the historical impacts of weather and climate recorded formally within the sector? [If so, how, and where (internally, externally)?] Are the impact data available publicly?*

6.3. Are there any climate-related critical thresholds that are of interest for the sector?

7. Which weather and climate hazard datasets and tools do you use when conducting research in this sector? Why do you use these?

8. Does the sector focus more on using climate data [that is, raw data from the models] or climate information [that is, processed data, or products derived from climate data]?

- If “climate information”, Q8.1
- If “climate data”, Q8.2

8.1 Why do you think they don’t use climate data?
8.2 Does the sector use any particular metrics, indices or indicators in their weather management / climate planning?

9. [Remind them of their answers to Survey Q11&12] Do you perceive any gaps in understanding in the sector, or in the tools and information currently in use in the sector?

Use of climate information

The next few questions are about the use of climate data and information **in the sector where your research is focused.**

10. Does the sector use historical climate/weather data or information (that is, information or data about past weather/climate)?
    - If yes, Q11
    - If no, Q14

11. What data or information is used and from where is it obtained?

12. What is it used for?

13. Which time period in the past is of most interest to organizations in the sector?

14. [Remind them of their answers to survey Q8] Does the sector use data or information about the future climate?
    - If yes, Q15
    - If no, Q18 OPTIONAL or Q19

15. What data or information is used and from where is it obtained?

16. What is it used for?

17. Which time period in the future is of most interest to organisations in the sector?

18. *[OPTIONAL – only use for respondents saying "yes" to Q8 and/orQ10 and/or Q14] [Remind them of their answers to survey Q9] Thinking back to your answers about the past and future climate information used in the sector, can you comment on why this particular information is used, instead of information from other sources)?*

What PRIMAVERA could provide

The next few questions are focused specifically on the current project, PRIMAVERA.

Types of information

PRIMAVERA will provide access to derived products, guidance, visualisations, training, and sector-focused information. Earlier, I asked about how organisations in your sector manage weather and climate issues at present, and which tools and data they use to do that. Thinking about your answers to those questions, what other types of weather/climate information products and support do you think would be useful from PRIMAVERA? There are four categories of information I would like you to consider. [Remind them of their answers to survey Q14]

19. What guidance and descriptive information would be useful? In what format?

20. What data and technical (specialised) information would be useful? In what format?

21. What visualized information would be useful? In what format?

22. What training materials and activities would be useful? In what format?

Temporal/spatial scales; lead time of information

23. [Remind them of their answers to survey Q11 & Q13] One of PRIMAVERA's main aims is to provide climate information at a finer spatial scale through use of higher resolution climate models. By finer scale I mean at a resolution of typically 25km. This higher spatial resolution can better simulate certain aspects of climate and climate change.
    - In your survey answers you suggested that information at this kind of spatial resolution [would/might be/would not] be useful to your sector. Please can you tell me more about the reasoning behind your answer?

24. [OPTIONAL] [Remind them of their answers to survey Q11] When you're using or thinking about climate data or information in your work, what spatial scale would you usually focus on?

25. When you're using or thinking about climate data or information in your work for the sector, how granular is the time resolution of the data that you would usually want to use?

Climate change opportunities [optional]

The next two questions are about opportunities from climate change.

26. [OPTIONAL] Do you think there could be any positive impacts/opportunities related to climate change for your sector?

27. [OPTIONAL] Thinking about how your sector manages weather and climate now, do you have any ideas how they might capitalise on those potential opportunities?

Closing

Some final questions before I conclude the interview.

28. Is there any other information which you feel would be useful to pass on to me in the context of this interview?

29. Should I invite someone else from your organisation to participate in an interview? Please give me the contact details of anyone who might be suitable.

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