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PRIMAVERA

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

Deliverable D11.5

EVALUATION REPORT OF PROJECT OUTCOMES BY END-USERS

Deliverable Title	D11.5 Evaluation report of project outcomes by end-users	
Brief Description	“This deliverable is part of T11.4. Evaluating how the project outcomes strengthen the competitiveness and growth of companies (Lead: BSC, participants: MO, UR, KNMI). Final meetings will be prepared and carried out with all users who were initially approached. A full evaluation (D11.5) will be made of the value, relevance and usability of the project outcomes for the users. Any limitations in the results will be evaluated and areas for on-going research to address the identifies gaps will be documented.”	
WP number		WP11
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PRIMAVERA

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Deliverable D11.5 provides user evaluation of the project, estimating the value, relevance and usability of project outcomes for users. There is a particular focus on remaining limitations and challenges, as recommendations for future research. The results are obtained from qualitative analysis of interviews with key users. The results are complemented with inputs from the final project (online) workshops.

The key values recognised by users could be grouped under two categories:

(i) *The PRIMAVERA experiment design*, including multimodel and ensembles, resolution and the global dimension.

(ii) *Bringing results to users*, including the coproduction process and users' pioneering of application of this novel knowledge.

Key stakeholders who are expected to benefit from this new knowledge are from water, energy, (re)insurance and agriculture.

The key challenges recognised by users involve: data quality, resolution, data availability & accessibility, limited period of model runs and challenges related to coproduction.

The final workshop where we planned to have a roundtable discussion about value added by PRIMAVERA and remaining limitations, was cancelled due to the COVID19 crisis. A virtual counterpart was organised instead. Although the participation and dynamics of discussion was affected by the online setting, we still obtained some interesting insights, supporting findings from the interviews.

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)*		x
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)*		x
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)*		x
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)*		x
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)*		x
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)*		x
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)*	x	
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)*	x	

3 Detailed Report

3.1 Introduction

Deliverable D11.5 provides user evaluation of project outcomes, estimating the value, relevance and usability of project outcomes for users, as well as identifying remaining limitations and challenges. The report starts by showing how the project provided value to users: (i) through the coproduction process, including users' involvement and engagement and knowledge co-development, and (ii) by informing the design of the second phase of the project experiment with findings about user needs and expectations.

The results presented in this deliverable are obtained from qualitative analysis of interviews with key users. The results are complemented with inputs from the final project (online) workshops. The final workshop where we planned to have a roundtable discussion about the value provided by PRIMAVERA and remaining limitations, was cancelled due to the COVID19 crisis. A virtual counterpart was organised instead. Although the participation and dynamics of discussion was, to some extent, affected by the online setting, we still received some interesting insights, supporting findings from the interviews.

One limitation of PRIMAVERA experienced by the project user engagement team was related to engagement of different sectors. Namely, sectors such as energy, insurance or water management, that are more advanced in using climate data and services, were those with which we managed to establish the strongest links. With an apparent interest in novel climate data and complementary previous experience, our set of champion users clearly showed that the project is relevant for more 'technical' users with pre-existing knowledge, skills and interests.

Thanks to the curiosity and technical knowledge of our users, as well as the support that they received from their companies for investing time in knowledge coproduction, on the one side, and time devoted to coproduction by the project impact scientists, on the other, we brought PRIMAVERA data to the context of private companies. Still, these were only isolated cases and of a trial nature. Given the limited number of the use cases of PRIMAVERA data beyond academia, it was difficult to speak about PRIMAVERA's role in strengthening the competitiveness and growth of companies (T11.4). We hence limit this report to the more general user estimation of the added value of the project outcomes and the remaining limitations.

3.2 Adding value for users

To develop useful and serviceable knowledge and add value of project outcomes to users, we applied a coproduction approach in PRIMAVERA. The approach included three phases: *engagement*, *involvement* and *co-development*, and applied multiple participatory approaches and communication tools. The three coproduction phases built on and interacted with each other as the coproduction process developed. The *engagement* was achieved through various communication channels for raising awareness about the available or emerging climate information from PRIMAVERA. Researchers and different knowledge agents, including potential users of the PRIMAVERA data, were then involved in more profound knowledge exchange – the *involvement* phase. In this phase we conducted a survey, interviews and meetings with users. Finally, the process of new knowledge co-development was achieved in tailored, often one-to-one, interactions, between scientist and users *(*Bojovic et al., forthcoming*)*. Throughout the coproduction process, we gradually involved more "specialised" users: from the broader stakeholder group that we informed through the awareness raising campaign, then on to potential users with whom we exchanged knowledge, and finally to define a set of champion users who co-developed the new knowledge and pioneered its use.

The initial activities within the engagement and involvement phases of our coproduction process aimed to collect information about user needs for new climate information (D11.6), as well as building a community of PRIMAVERA users. Within the involvement phase, we conducted a survey that had 83 participants, and 47 follow-up interviews. Inputs from users and the analysis of the first phase of the project experiment simulations (Stream 1) were considered to characterize end-user based recommendations for climate information. Namely, designing the second phase of PRIMAVERA simulations (Stream 2) was informed by Stream 1 and by inputs from the user community. In this way Stream 2 shaped some of the project outputs according to user needs, adding value for future users. The main requests and themes identified are as follows:

- **The potential user community is diverse and inhomogeneous.** There is no single set of 'climate simulations and data' that satisfies all users and sectors. Moreover, the user-community – even within a particular application sector – should not be seen as a group with a single well-defined set of climate information needs.
- **Prioritization of present day vs future scenario simulations.** Characterization of the present and very near future is very important for many users, as often planning horizons are only a few years ahead. However, the 'present day' is often interpreted more strictly than is common in the climate community, i.e., it means as close as possible to the present date, rather than simply 'not pre-industrial' or even a standard baseline such as 1971-2000. There is nevertheless an appetite for longer horizons from some users (even beyond 2050), particularly associated with large-scale infrastructure planning. In all cases, statistical robustness is important for subsequent climate impact analysis, i.e., ensemble size must be sufficient.
- **Realism is important.** In general, users are concerned about the impact of climate upon their interests (e.g., rainfall into a target catchment) rather than the underlying climate itself (e.g., representation of precipitation in storms). We thus recommended that the Stream 2 simulations should attempt to provide surface data output with spatial and temporal characteristics as close as possible to the available observations at specific locations.
- **High frequency/high resolution surface output data is valuable.** Some users require high (or very-high) frequency data for onward modelling (e.g., energy and insurance applications) that cannot be 'recreated' from coarser frequency GCM output. WP10/11 research has confirmed that very high-frequency GCM output data (~1h or ~3h) contains additional 'information' compared to more standard frequencies (~6h) which can be utilised by many users (e.g., wind- and solar- energy, power system modelling). 6-hourly surface data were requested as a minimum, and 3h- or even hourly frequency output should be preferred where possible. This high frequency data was recommended as part of the standard output package of Stream 2. We are, however, aware that global high frequency surface data output – and its transfer and storage at JASMIN – is a challenge for many modelling groups. However, data for the

variables that are commonly relevant for user applications are likely a small subset of the total data generated during simulation runs. Here again, closer collaboration between champion users, involved in co-development of case studies, and project scientists would be crucial for enabling access to data.

- **Some expert users – particularly those who are already familiar with working with climate model or reanalysis data – would value access to the raw data rather than processed diagnostics or visualisations.** There remains, however, considerable diversity between different user groups on their ability to analyse 'raw' climate data and many groups remain inexperienced in terms of the challenges involved (e.g., many TB of NetCDFs, the need for and application of bias correction techniques, etc.).
- **For some applications, e.g., modelling power output from solar photovoltaics, the use of 360-day calendars by some GCMs is problematic.** For some applications it is possible to compensate for this (e.g., use of weather generators and/or delta-methods) but, where possible, a 365-day calendar should be preferred.
- **Run length and ensemble size matters for 'climate impacts' as much as it does for 'traditional' climate science.** Users typically wish to characterise particular types of event (often extreme events or involving changes in high-frequency variability) and the impact they have on their sector (typically through a complex series of impact models). If the GCM output dataset is too short/small to robustly identify natural variations or trends in 'pure climate variables' (e.g., temperature or precipitation over Europe) then it is likely also too small to identify natural variations or trends in the 'climate impacts' (e.g., wind power, insurance losses) which depend on them. Surface meteorological data essential for climate impact studies should therefore be provided throughout the whole of every model simulation rather than in limited 10-year 'time-slice' windows for a few ensemble members.
- **The resolution at which some users require data is still out of reach of the state-of-the-art global climate modelling undertaken in PRIMAVERA.** For drainage modelling, for example, users desire driving data for their models even at ~metre-scale resolution.

As we see from the identified requirements and themes, there is no single recommendation from WP10/11 for adding value to climate data to bring it closer to user needs and decision-making contexts. However, a few aspects of Stream 2 improvements clearly address the requirements identified in early stages of the user engagement and involvement process, as well as confirmed later in collaboration with champion users. These key factors of Stream 2 design include:

(i) Increasing the ensemble size – some models introduced three or more ensemble members to support climate impact assessment, i.e., to help better detecting climate signals against "noise" associated with inter-model spread (e.g., different model responses to identical climate forcings) and natural climate variability. The ensemble size was increased as a result of analysing the Stream 1 simulations where the effect of resolution was difficult to distinguish from the inter-model differences and to allow more accurate conclusions to be made about the effect of resolution.

(ii) Retaining the most useful high-frequency variables from Stream 1 – to allow the additional ensemble members to be run, the size of the data volume to be output had to be reduced. To enable climate impacts to be examined, the most useful surface meteorological variables at the highest frequency of 3 or 6 hourly that each model could support, were retained in the Stream 2 data.

3.3 User evaluation of project outcomes

3.3.1 Methodology

To evaluate the value, relevance and usability of project outcomes, as well as remaining limitations, we conducted semi-structured interviews with PRIMAVERA users and planned to conduct an evaluation workshop at the end of the project.

We developed the interview guide which we tailored to each user or research study. In the interviews, we asked about particular use cases, how PRIMAVERA and other climate data was used, if there were any decision-making processes that could be improved with this data, and what were the challenges that PRIMAVERA could not address (the general guide is available in Annex 1). The interviews were conducted using the GoToMeeting platform. With consent from the interviewees, the interviews were recorded with the purpose of making the interview transcript, and deleted afterwards, in accordance with the General Data Protection Regulation (GDPR). We conducted 7 interviews with: a user from the energy sector, a user from reinsurance, a researcher in energy, two researchers in agriculture and water, and two climate scientists who applied PRIMAVERA data in IPCC and KNMI Scenarios. Unfortunately, it was not possible to conduct interviews with any users from transport.

We used the qualitative analysis software MAXQDA to analyse the interviews. In this processes we used the coding technique, which includes labelling and organising of the information in the interviews to identify our themes of interest. In particular, we looked for mentions of PRIMAVERA and other datasets, decision-making processes, stakeholders, added value, competitiveness and challenges (Figure 1).

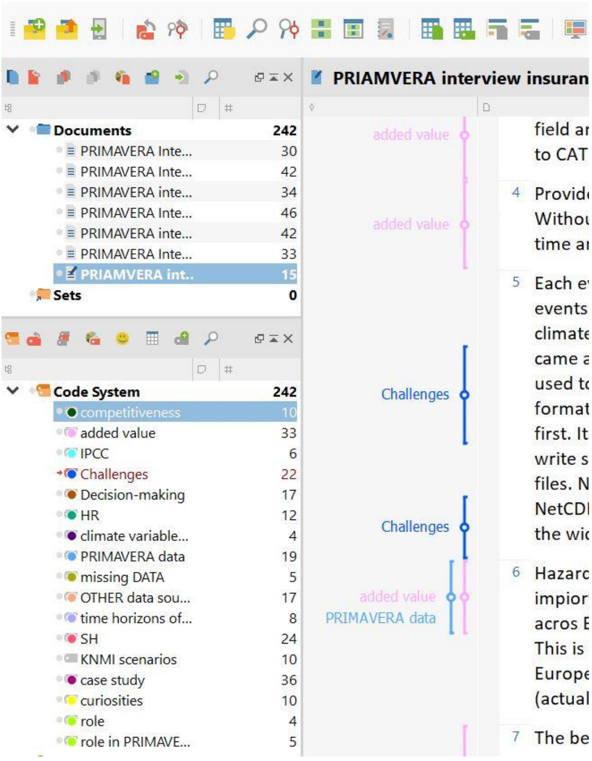

Fig. 1. Screen shot of MAXQDA window with the coding system for the PRIMAVERA interviews.

The idea of the final evaluation workshop was to discuss the added value of PRIMAVERA outputs and remaining challenges in a round-table setting. It was originally planned to be held at the EGU2020, and booked as a splinter session titled: “The PRIMAVERA project: From high-resolution climate modelling to user applications” (Figure 2). We were planning to invite project stakeholders and users, who have steadily provided feedback throughout the project. However, due to the COVID-19 related restrictions of movement, EGU2020 took place online. We were informed by the organiser that splinter sessions were not considered part of the official EGU agenda and, hence, no online counterpart was provided. Instead, we prepared the PRIMAVERA online workshop that was hosted in May, with four presentations from three PRIMAVERA scientists and a champion user. Other inputs about the added value and limitations of PRIMAVERA results come from the Energy Workshop organised in June 2020 and a transport workshop held in Ireland in February 2020.

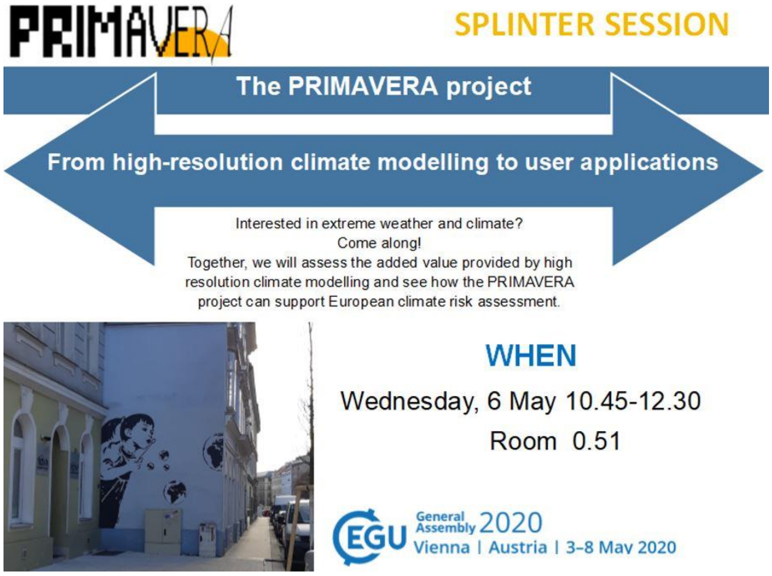

Fig. 2 EGU2020 splinter session invitation

3.3.2 Results

The project proved relevant for scientific and “technical” users with pre-existing knowledge, skills and interests, as confirmed by the profile of the interviewed users. Our coproduction framework, in particular the engagement activities, targeted a broader audience. In this sense, we prepared communication and dissemination materials and activities, such as the video, factsheets and webinars. However, our champion users who participated in the co-development stage were all people with scientific backgrounds.

3.3.2.1. Added value

Based on the analysis of the interviews, we grouped the aspects of the added value of PRIMAVERA under the following categories:

A) Global dimension

Our users recognised the added value that global climate data provides. Two reasons were given. First, some changes in atmospheric circulation need global perspective (e.g., ENSO). This means that there is some information that can only be provided by global climate simulations. An example is the risk from tropical cyclones hitting Europe in the future. Information about tropical cyclones is very important and relevant, given their potentially large impacts on economic sectors in Western Europe, such as agriculture. Our interviewees argued that there was no other way to estimate this threat, but by using high resolution global climate models.

For the analysis of climate change in non-European regions, global runs are also an added value. One of our champion users works for a company that has energy assets both in Europe and on other continents, and recognised this aspect as very useful. Another user provides information to stakeholders who have assets across the globe and are interested in correlations between hazards. Another analysed case study was focused on Southeast Asia. For this region, CORDEX and other regional datasets are less robust than in Europe, according to our interviewee. Having reliable and high-resolution data available for this region was the key motivation for this user to apply PRIMAVERA data.

B) PRIMAVERA experiment design

The PRIMAVERA experiment gives a unique opportunity to analyse results from long (1950-2050) global simulations, produced in a consistent way, under a single protocol (HighResMIP) in ensemble mode: both multi-model and single model ensembles. Hence, PRIMAVERA reveals some of the elements of the "*big high-resolution enigma*", according to our scientific user. This user saw the added value in the fact that all the models are run at both low resolution (LR) and high resolution (HR) and there was no extra tuning between these runs, or changing of the parametrisation. For this reason, "*although all the models are different, if we see an increase in e.g., drought as we move from low resolution to high resolution, we can make the conclusion that increasing resolution will affect the occurrence of droughts*." (user scientist).

Another user appreciated the opportunity to compare the baseline scenario, constant 1950s forcing, with the RCP8.5 scenario. This allowed the user to look into climate risk, to see how the risk from a certain event changes over time, and with different climate change scenarios. Yet, the other user acknowledged the benefit of seeing the future climate change dynamics over time and not just as delta.

C) Multimodel

The multimodel aspect of the PRIMAVERA experiment design was in particular emphasised by a few users. The fact that both historical period and future runs are combined and available for six European GCMs was recognised as providing added value. This approach helps construct a coherent message and provides another line of evidence e.g., for IPCC reports. PRIMAVERA data can be used to challenge or corroborate existing hypotheses in the literature, and to explore the dependence (or not) of results on choice of model or number of available models. Having access to the latest datasets is a critical component for IPCC. This helps providing reliable climate information using different lines of evidence.

In addition, the global multimodel setting provides much-needed data for some regions where CORDEX or other datasets are less robust than in Europe, e.g., in Southeast Asia where the CORDEX data is available only for a few models.

D) Resolution

As the high point of PRIMAVERA, high resolution was unsurprisingly recognised by all the interviewed users as providing added value.

Impact models (and modellers) are interested in the regional/local scale and need HR. For example, for a hydrological model, a user needed high temporal resolution, which was previously only partly available from CORDEX. Downscaling in time is much more difficult than in space, hence, the high temporal resolution in PRIMAVERA was acknowledged. Also, users confirmed that going to even higher resolution, which is needed for some very HR hydrological models, is easier if downscaled from already high-resolution PRIMAVERA data.

One particular example of the importance of HR was given related to the occurrence of droughts in Western Europe (as discussed in D10.4). Some PRIMAVERA models (e.g., EC-Earth) suggest that occurrence of droughts will be larger and stronger than what LR CMIP6 type models show. HR enhances the anticyclone over the UK and spring drying, increasing the chance of dry summers.

E) Coproduction

While project scientists have available time and resources for working (with users) on the project data, stakeholders are expected to volunteer their time. Thus, for stakeholders to find PRIMAVERA data useful, it is not only the issue of the huge amount of data – which demands computational capacity sometimes beyond users' availability – but also the time and effort needed for their manipulating and using PRIMAVERA data. Accordingly, our champion users recognised that the coproduction process, in particular the co-development step in which the project impact researchers and users worked together in mutually agreed one-to-one settings, brought an added value for them. For example, our scientists downloaded and pre-processed data that users then used in their models, and decision-making settings. In other cases, users acknowledged the time that scientists spent to explain to them PRIMAVERA outputs in detail, and to walk them through the data.
"*No user would want to have several Tb of data for all variables and the whole globe.*" (Energy user).
"*Having access to one of the leading scientists in the field and outputs that we can easily digest and relate to CAT models is invaluable*." (Insurance user)

F) Pioneering use

The possibility for pioneering the use of novel data was acknowledged as beneficial by some users. Still, a user needs to be "risk-tolerant" as it is difficult to assess how much value this novel data can add to one's business, while data is still being produced and its added value is yet to be assessed. One user stressed as the advantage that he now knew more about data than their business competitors, as they were first to use new data, before others. Still, this "*small difference is often not a decisive element that will bring you a new project, it can however be a plus if the investor recognises it. The little piece of extra knowledge*" (Energy user).
"The win for us is being recognized that we are working with some of the leading scientists in the field, and we are sharing this data" [with other stakeholders in the field] (Insurance user).

The user from SE Asia was pioneering the use of PRIMAVERA data in this part of the world.
To motivate more such 'early adopters', the interview participants recommended to have more showcasing of excellent work achieved across the spectrum of PRIMAVERA activities. Visual presentations of examples where PRIMAVERA models have good skill and where the HR added value is obvious were mentioned. One such example of showcasing PRIMAVERA data was achieved with the Data Viewer (D11.4). Data Viewer was launched in February 2020 and by July 2020 was visited for 1100 times. This high number of the page visits is not surprising, given that one of the most popular @PRIMAVERA_H2020 tweets was the one that introduced the PRIMAVERA Data Viewer (see more information in section 3.3.2.4).

3.3.2.1 Added value for whom?

One of the questions discussed in the interviews was about the main stakeholders that our users provided PRIMAVERA data-based information to. Interviewees listed stakeholders from water, energy, (re)insurance and agriculture. Four of our users collaborated with water management authorities, including water boards and national and regional authorities. Two users were in contact with the energy sector, in particular hydropower companies and transmission system operators. One user was from an insurance broker, linked to the insurance and reinsurance sector. Two users were doing data analysis relevant for the agricultural sector and farmers' associations.

In the long run, the information obtained from PRIMAVERA data could inform different policy makers, in particular through inputs that our users provide to adaptation plans, IPCC, and the KNMI'21 scenarios. Speaking about the type of decisions that could be informed, our interviewees underlined climate change adaptation policy, and in particular water resources adaptation. The latter includes different domains including navigation, hydropower and water infrastructure, such as drought and flood protection infrastructure. A spectrum of different information would be useful for these decisions. For hydropower, for example, any overall decrease in annual discharge is very important information. Then again, for water infrastructure, information about extreme events, such as severity of flood or drought is what matters. Also, many water users are interested in river discharge. Combining PRIMAVERA data with hydrological models would enable simulation of river discharge, assuming the relevant inputs were available from the data

3.3.2.2 Remaining challenges and limitations

One limitation of PRIMAVERA was experienced by the project user engagement team. We tried to engage different sectors, but not all were equally approachable. Sectors such as energy, insurance or water management, that are more advanced in using climate data and services, were those with whom we managed to establish the strongest links. With an apparent interest in novel climate data and complementary previous experience, our set of champion users clearly showed that the co-development stage was limited to more "technical" users with pre-existing knowledge, skills and interests.

Originally, we planned to analyse limitations of PRIMAVERA and remaining challenges for high-resolution climate modelling with users in the EGU2020 workshop. After the workshop was cancelled we moved this discussion to the interviews. We can classify the remaining challenges into five categories.

A) Data quality

Generally, the reduction of systematic error persists as an issue in PRIMAVERA data. More specifically, some users observed large local differences when they did local evaluation, e.g., when analysing specific smaller catchments, at the grid-cell level. Then again, when looking at regional averages the results looked favourable.

The scientific users stressed the need for larger ensemble size. Larger model ensembles allow the probing of different types of uncertainty and better understanding of the impact of natural variability. Although the ensemble size increased in the Stream 2 experiment – e.g., from one to three members for some models – an appropriate understanding of the uncertainties in some phenomena, such as droughts, demands large ensembles. The ideal ensemble size would hence depend on the variable, resolution, timeframe and the phenomenon under investigation. Performing more simulations and handling these simulations in a more efficient way would certainly demand more funding to hire people and obtain computing time and storage. Human resources are not only important to run simulations, but also to examine them carefully and perform tuning to improve representation of the most relevant processes.

B) Resolution

PRIMAVERA provides the latest generation of high-resolution climate models. Still, the resolution of other types of models that impact researchers use, such as hydrological models, is ever increasing. Even the HR data from PRIMAVERA is insufficiently high for some of these models. In addition, data should ideally be at the same resolution as the information it wants to inform. Hence, for some local decision-making contexts, information is needed at very high resolution.

Time resolution, although much higher in PRIMAVERA compared to commonly used lower resolution or regional climate data, was still insufficient for some research, such as the research on energy network development planning. It was though acknowledged that the requested temporal resolution of ≤1h is unrealistic given the current climate models' capabilities, and the current computing facilities on which they are run and their output stored.

C) Data availability and accessibility

Some of the business users and researchers cited the access to PRIMAVERA data as challenging. In particular, the storage mechanism of PRIMAVERA is not the most user-friendly and getting access for those with non-affiliated PRIMAVERA email addresses was not straightforward at the beginning. It thus took some time for certain users to get credentials for accessing JASMIN. Even so, there were some further JASMIN requirements, e.g., a fixed IP address that was not available at the university from which one user was granted the access, which further delayed their access to PRIMAVERA data.

Related to data availability, the project faced delays in production of future runs (as discussed elsewhere). Some of the agreed collaborative activities suffered from this delay, since we needed to readjust plans for collaboration on data testing and application. For example, with one of our first champion users the collaboration started in the first half of the project. At that time, only data from historical runs was available, while future period data came much later. The co-design process hence took place during a few separated instances, over a period of 2 years. This demanded additional efforts from the user's and scientists' side to remember what was done before and reinitiate the work.

Another aspect of data availability was related to the size of data. Namely, some modelling groups needed to sub-select the data they could upload on JASMIN, as their upload capabilities were bandwidth-limited. In some cases, users needed data or resolution which was not within the selected data available on JASMIN, which involved additional steps of asking for access to this data.

Finally, the standard for sharing climate data, NetCDF files, is not necessarily the standard data format for some industries. "*NetCDF format might be a bit of the roadblock for the wider insurance industry*." (Insurance user). However, it was acknowledged that the industry should get used to and accept the best format for climate data.

D) Limited future (and past) period

For some decision-making settings, there is an obvious need for information until the end of this century, e.g., for long-term adaptation planning. Some researchers argued for the future data extending out to the end of the century which would help them see better the long-term climate change impact.

The insurance industry is interested in particularly large datasets. Looking at extreme risks, they are used to at least 200 years long datasets. "*Having more data would reduce uncertainty in the tail*." (Insurance user).

In addition, one user showed interest in having future data for different RCP scenarios.

E) Challenges for coproduction

The contribution from users is in-kind. This additionally narrows the set of users apt for the coproduction process to those who have available time and support from their institutions to devote time to coproduction. Ideally, users could be more formally involved in the project which would give them additional time and other resources for coproduction. Finally, given the high scientific uncertainty and the fact that this new data is still under development, while its added value is yet to be fully assessed, only users with previous experience and substantial understanding of climate modelling and/or risk-tolerant users were ready to collaborate.

3.3.2.3 Insights obtained from users from workshops and webinars

3.3.2.3.1 Feedback from the final project workshop

After the cancellation of the physical EGU2020 meeting and our splinter session that was intended as the final project workshop, we organised an online workshop/webinar titled: "THE HIGH-RESOLUTION REVOLUTION: An Overview of PRIMAVERA Science, 'Big Data' Management, and Added Value for Users". The presentations in the webinar aimed at providing an overview of the project results and included: (i) Overview of the results achieved in PRIMAVERA (project coordinator), (ii) Application of PRIMAVERA results in climate impact modelling of the Upper Danube River (project champion user), (iii) Overview of Tropical Cyclone Activity in PRIMAVERA/HighResMIP simulations (project scientist) and (iv) Data management and accessing the long term data archives (project scientist). After the presentations we opened the floor to 16 webinar participants. Our main topic for discussion was the remaining challenges and lessons learnt from PRIMAVERA. The main conclusions were in line with our findings from the interviews with users:

A) The ensemble size matters

The ensemble size is particularly important for this type of experiments. The way ensembles were run in PRIMAVERA was not homogeneous across the whole community. The project could have been less ambitious in terms of all the various model formulations (i.e. doing less model development and testing of new physics schemes) and be more ambitious in terms of ensemble sizes.

B) Coproduction

It was agreed that there was not sufficient time for user involvement in PRIMAVERA and also that PRIMAVERA data are not for “direct” use by users, e.g., the HR models are not tuned, since the aim was to understand resolution. Hence, the greater importance of the coproduction process was recognised.

There was a suggestion to have the user involvement in this type of projects in two instances: the first very early in the project and the second later when the simulations are completed. Longer project duration, perhaps 5 years, could be more convenient in this case. It was also recommended to try to provide direct funding for user involvement in future projects.

C) Data Access

Only the whole global domain can be downloaded from ESGF, which is not practical for many users who would rather download data for a particular selected domain. For users to be able to subset data, the best approach would be to obtain a JASMIN account which enables them to work directly off the data archive. As discussed above, obtaining a JASMIN account could require a few additional steps and could be a drawback for some users.

D) High resolution

Participants recognised many positive impacts of HR. Still, they strongly recommended to prepare a synthesis report on aspects that have and have not been improved by resolution. Having an insight into which climate phenomena were impacted by HR and what are the remaining challenges would be beneficial for the scientific user community. Much could be learnt from PRIMAVERA about aspects that did not improve with resolution.

3.3.2.3.2 Transport sector workshop

The transport sector workshop was held with Transport Infrastructure Ireland (TII), Met Éireann, and the Irish Government Department of Transport, Tourism and Sport (DTTaS). We welcomed 11 participants to a lively and engaging day talking about climate impacts, vulnerability, risk and adaptation, using PRIMAVERA work as a way to highlight relevant topics. One aim of the workshop was to engage TII to participate in a detailed case study for PRIMAVERA D10.4, however this was ultimately not possible due to additional time pressures (for scientists and users alike) arising from the COVID-19 pandemic. Nonetheless, we obtained information from the workshop that was used in D10.4. We received some pleasing feedback after the workshop: “*Thanks for your great work putting the day together*”; “*Good and well-thought-out interactive sessions*”; “*I can see the considerable outputs from the PRIMAVERA project being of value to many*”.

3.3.2.3.3 Workshop on energy-climate modelling

An online workshop "Next generation challenges in Energy-Climate modelling" was held on 22nd and 23rd June 2020. It was hosted by the University of Reading with David Brayshaw as the lead convener. The workshop brought together an international group of researchers working at the interface between climate science and energy applications and was well subscribed (140 applications) and attended (>70 participants each day including participants from the US, EU, Australia, Africa and others). The participants were predominantly drawn from academia with a small but significant industry and policy presence, and included a very strong representation from energy-science experts.

The workshop had two primary goals: (i) to build a deeper engagement across the "energy" and "climate" research communities and (ii) to identify and begin to address the scientific challenges associated with modelling climate risk in energy systems planning and operations. One of the keynote talks was provided by the PRIMAVERA impact scientist Paula Gonzalez.

Feedback from workshop participants was overwhelmingly positive and there was a clear appetite for further events (e.g., another workshop in ~12 months) and/or provision of training in the form of online materials and summer schools (regarding both energy- and climate-science) to promote community building. The workshop's core organising team (16 people) is continuing to meet regularly and is in the process of distilling the outputs and determining follow-up actions. It is, however, intended to publish a short workshop report (target: Bulletin of the American Meteorological Society), and there is potential for one or more longer "review" or "perspective" publications which are being explored.

3.3.2.4 Twitter

The use of the @PRIMAVERA_H2020 Twitter account (created in August 2017) has been helpful in the second half of the project, for engaging informally with users and interested parties. More information about the use of Twitter will be provided in D11.7. At the time of writing (June 2020), @PRIMAVERA_H2020 has 276 followers, with the number of followers having doubled approximately every 12 months.

The most liked @PRIMAVERA_H2020 tweets are shown in Figure 3. Aside from the general pinned tweet advertising the project's capabilities (left), users engaged most with the tweet introducing the Data Viewer (right), which is clearly a popular output from the project – not surprisingly given its visually appealing presentation of useful scientific information.

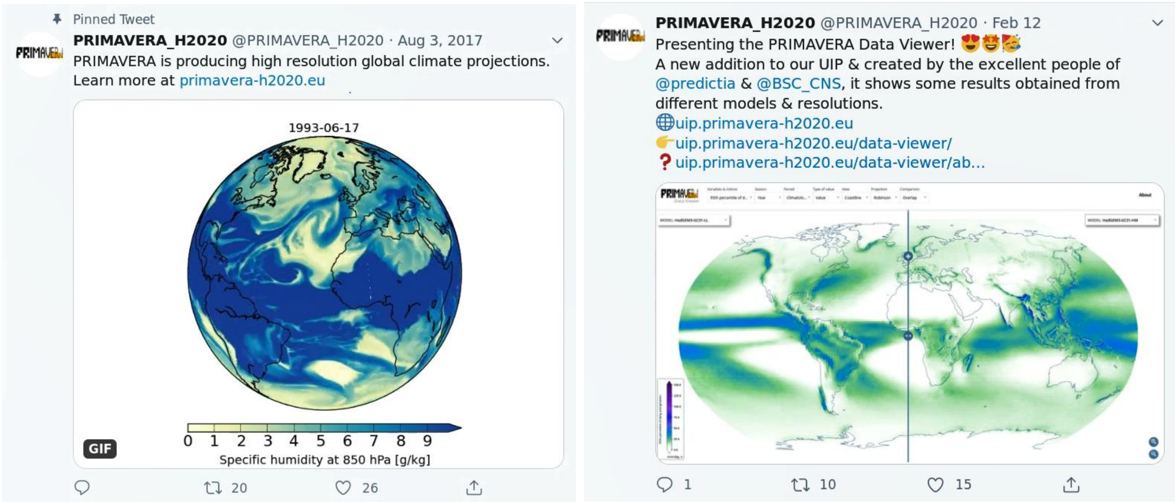

Fig. 3. Most liked @PRIMAVERA_H2020 tweets

In the final month of the project (July 2020), we plan to undertake a short retrospective Twitter campaign, looking back over the project and its outputs and successes, mainly by refreshing previously-tweeted materials (e.g. the project fact sheets and interesting research papers). Additionally, the outputs from D11.7 will provide useful “PRIMAVERA by numbers” information that can be used on Twitter to illustrate the project’s value.

4 Lessons learnt

- **Project interdisciplinary collaboration.** The project consortium involved scientists from various disciplines and with diverse expertise. Still, the project structure divided climate and data scientists (who were concentrated in WPs 1-6 and 9) from impact scientists and user engagement and communication experts (who were concentrated in WP10/11). Transversal collaboration between project scientists would speed up the process of knowledge transfer within the project and, hence, facilitate interaction with stakeholders and knowledge coproduction. A key challenge was in understanding and communicating the nature of Stream 2, and its associated improvements, to users. At the start of the project (e.g., as noted in the project video), it was understood that the main improvement would be in providing even higher-resolution (both temporally and spatially) data than in Stream 1. However, the scientific decisions taken in the project changed this direction somewhat (for good scientific reasons), making the communication about the achieved improvements in Stream 2 more challenging. Although we are still learning about how to make the most of the interdisciplinary teams that are involved in climate services projects, some of the collaborations established in PRIMAVERA brought very fruitful results. The communication between WPs 10 and 11 was strong, frequent and maintained throughout the project, and a clear example of its success is the development of storylines and narratives, described in D10.4.

- **Knowledge coproduction**. Knowledge coproduction in climate services should provide greater quality, compliance and usability of products and services (Bremer and Meisch, 2017; Lemos and Morehouse, 2005; Moser, 2016). Still, given the very scientific and experimental nature of the project, project outputs were relevant mainly for scientific and "technical" users with pre-existing knowledge, skills and interests. Perhaps, it was too ambitious to expect to genuinely engage various sectors in such a technical project.

  Our champion users are from the energy and insurance sectors – the forerunners of the application of climate data – with an evident interest in this new type of climate data and complementary previous experience. This clearly shows that the project value is limited to more technical users with pre-existing knowledge, skills and interests.

  Thanks to the curiosity and technical knowledge of our users, we brought PRIMAVERA data to the context of private companies. Still, these were only isolated cases and of a trial nature. Given the limited number of use cases of PRIMAVERA data beyond academia, it was difficult to speak about PRIMAVERA's role in strengthening the competitiveness and growth of companies.

  Besides the bias in the sample of champion users, the other activities of our coproduction projects, such as engagement though communication (e.g., conferences, webinars, Twitter, mailing list), allowed other involved stakeholders to deepen their understanding of the project while at the same time assuring the project's comprehension of the needs and capacities of stakeholders.

- **Project timing**. Delays in the availability of the PRIMAVERA simulations together with occasional delays in getting access to non-affiliated PRIMAVERA email addresses to JASMIN impacted user engagement activities. Better alignment between the planning of project scientific outputs and user-oriented activities could help mitigate this problem. One interesting suggestion was to split coproduction into an early project activity (knowledge co-exploration) and the later project activity (knowledge co-development).

5 Links built

Knowledge transfer and knowledge co-development with users requested strong links between project climate scientists and the user engagement team. In particular, WP11's user engagement team maintained links with WP10's impact scientists, who actively participated in the one-to-one collaboration with our champion users, and generally supported knowledge transfer.

Strong collaboration and the relationships with champion users built trust both within the user community and among project scientists. Through the collaboration and the coproduction process, users deepened their understanding of the project and could move this novel knowledge from the scientific realm to real-world decision-making processes. Close collaboration also built trust among the project scientists, who were initially more reluctant to share modelling outputs freely before these had been published in scientific journals. The strong links built between PRIMAVERA scientists and champion users led to true partnerships in some cases. Some of these collaborations will continue after the project ends, bringing scientific knowledge ever closer to real-world decision-making processes.

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7 ANNEX 1 PRIMAVERA INTERVIEW GUIDE

for D11.5: *Evaluation report of project outcomes by end-users*

Interviewee: Name and institution

Use case: title of the case study

Section 1) Introduction/Background

1. Please tell us about your professional role and your links to PRIMAVERA

Section 2) Research topic

2. Can you tell us more about your research?
3. What is particular about the use case?
4. How is this particular research/analysis done?
5. Please, identify who are possible stakeholders and users of your research
6. What are the climate variables of interest for your research? And what are the time horizons of interest?
7. Anything else of importance regarding your research case?

Section 3) Current use of climate information

8. What climate data do you currently use?
   - Weather forecasts?
   - Climate predictions?
   - Projections?
   - GCM or RCM or both?
9. In which context do you use climate projections?

10. What is the temporal and spatial resolution?

11. What are the issues/limitations you are encountering with the models/datasets currently available?

12. What do you think are the consequences of these limitations on:
    - your research activities?
    - potential stakeholders?

Section 4) PRIMAVERA data

13. How do you expect PRIMAVERA outcomes to improve your research?
14. How could stakeholders benefit from PRIMAVERA high-resolution models?
15. What are the decision-making processes that could potentially be improved with this research case? How?

16. How easy can this information be translated into decision-support?
17. What are important challenges that PRIMAVERA cannot solve?