S2S4E
Climate Services for Clean Energy

Research and Innovation action

H2020-SC5-2017

User needs and decision-making processes that can benefit from S2S forecasts

Deliverable D2.1

Final version

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About S2S4E

The project seeks to improve renewable energy variability management by developing a tool that for the first time integrates sub-seasonal to seasonal climate predictions with renewable energy production and electricity demand.

Our long-term goal is to make the European energy sector more resilient to climate variability and extreme events.

Large-scale deployment of renewable energy is key to comply with the emissions reductions agreed upon in the Paris Agreement. However, despite being cost competitive in many settings, renewable energy diffusion remains limited largely due to seasonal variability. Knowledge of power output and demand forecasting beyond a few days remains poor, creating a major barrier to renewable energy integration in electricity networks.

To help solve this problem, S2S4E is developing an innovative service to improve renewable energy variability management. The outcome will be new research methods exploring the frontiers of weather conditions for future weeks and months and a decision support tool for the renewable industry.

More information: www.s2s4e.eu

Executive Summary

This report, produced during the first nine months of the S2S4E project, aims at providing a comprehensive description of climate services users' needs and their decision-making processes in the renewable energy (RE) sector to understand how and if they can benefit from S2S forecasts. This was achieved in two steps. Firstly, an overview of the knowledge gathered during previous projects through interactions with users (chapter 1) that represented the starting point to structure the in-depth interviews subsequently conducted by S2S4E partners. Then the answers of the interviews performed were collected and analysed (chapter 2). The findings will support the development of the Decision Support Tool (DST) - becoming operational during the project and providing S2S forecasts – that aims to add value in users' decision-making processes. The major drivers identified are the financial gains or avoided losses. Observing the risks involved, the failure of a forecast would usually cause higher damages than the benefits of a successful one. Currently, in our sample, S2S information is used only qualitatively due to different barriers that are here investigated and translated into opportunities for improvement in the provision of S2S forecasts. In fact, as emerges from the analysis conducted in this report, there exist various decision-making processes that would benefit from a more systematic use of S2S forecasts.

Introduction

WP2 aims to get a deep understanding of how S2S forecasts can add value to the companies exploiting renewable energy (RE) sources. Renewable energy comes from natural sources such as sunlight, wind, or rain, which are not continuously generated and whose variation is currently uncertain. Both the generation and operational planning of renewable energies are strongly affected by weather and climate, which cause wide variations in energy supply and demand. Hence, reliable predictions for the forthcoming weeks and months on wind speed, temperature, radiation and precipitation, would be very useful to allow efficient energy management as well as in terms of strategic planning.

The final goal of the S2S4E project goes beyond providing plain forecasts. A Decision Support Tool (DST) will be made available to the RE sector, with relevant information on future climate conditions and expected performance of the assets, ready to be integrated into the decision-making protocols of RE companies.

To develop such a tool, feedback from the users must be taken into account to i) understand their decision-making processes and ii) identify how climate information can be relevant for those processes. With this in mind, an initial review of existing knowledge (Task 2.1) is offered in Chapter 1. This review aims at gathering the experience from previous initiatives and projects that have carried out user engagement activities to understand energy users' needs for climate services. Besides that, a series of interviews with the key stakeholders are reported in Chapter 2 to gain a more complete and detailed understanding of the usefulness of sub-seasonal to seasonal predictions and the potential economic benefits for their companies (Task 2.2). Contrary to other methods (e.g., survey), interviews provide a more in-depth understanding of the issues at hand by allowing the interviewees to share their knowledge and experiences (May 2011).

It is important to notice that the co-development process of the DST implies a learning phase for both users and scientists. This allows for understanding user needs and at the same time to explain them how and why S2S forecasts can add value to their decision-making processes. At this stage, users need to become aware of what it is feasible and the initial discussion helps to align expectations. For this reason, the report takes into account all the requests from users but the reader should notice that not all the suggestions will be implemented in the project.

Chapter 1
Review of existing knowledge

1 Review of existing knowledge

To date, different projects on climate services have used the interview approach to get information and feedback from users. The downside of applying this strategy in S2S4E is that many of the users have already been engaged in previous projects and there is some risk of producing user fatigue.

To avoid this problem, the main objective of Task 2.1 was to review the information derived from all the previous contacts with RE stakeholders - either producers, traders or transmission systems operators. Analysing previous outcomes constitutes the first step to know stakeholder needs in terms of climate data that have already been identified. This avoids asking repeatedly the same questions, highlighting the remaining gaps instead.

This insight has two main benefits. First, it allows T2.2 interviews to be solution-oriented instead of problem-centred, since the shortcomings of the S2S forecasts would have been already assessed. Second, the review of a diversity of feedbacks through time provides an assessment of the stakeholders' capacity building since 2011.

1.1 Methodology

In order to review the existing knowledge an initial list of EU-funded projects was prepared (Table 1). This list included projects with user-engagement activities related to the use of climate services for different sectors. This list is non-exhaustive and it does not reflect all the EU funded projects, but those that could have relevance for the energy sector.

After a general inspection of the projects in that list, only those with relevant information about user needs in the energy sector were reviewed (see list in Table 2) indicating the user engagement methods used, the sample size when available, as well as providing the reference to the reports with the results of the user engagement activities.

For each of these eight projects a general description of the project is given below and after that we have summarized the outcomes of those projects through the concept of "metauser". In this analysis, we use the term metauser to refer to a general user that summarises the inputs from different users and professional profiles gathered from different engagement techniques from non-specific surveys to workshops or detailed interviews.

Finally, the last section of the analysis profiles an energy sector metauser based on the synergetic aspects of the metausers of the different projects.

Table 1: Non-exhaustive list of EU-funded projects with user-engagement information

Project name	Included in review	Funding	Comments
CLIPS	NO	WMO	Old project (1995) on Climate Information and Prediction Services. It is the implementation part of the World Climate Applications and Services Program (WCASP).
RIMAROCC	NO	FP6	Both ROADAPT and RIMAROCC are old projects aimed at road management. There is indeed some information about climate change, but the stakeholders are road owners.
ROADAPT	NO	FP6	Both ROADAPT and RIMAROCC are old projects aimed at road management. There is indeed some information about climate change, but the stakeholders are road owners.
WATCH	NO	FP6	Focused on water and global change. No user-defined needs are reviewed. Stakeholders are mainly policy makers.
CIRCLE2	NO	FP7	Focused on assessing the impact of climate research at European institutions, mainly policy makers. There are some preliminary guidelines on best practices at engaging with stakeholders.
CLIM-RUN	YES	FP7	First attempts to engage users in the design of the interfaces. Some information in the deliverable 7.4 from RE sector.
ECLISE	YES	FP7	Deliverable 1.1 and 1.3 – User needs reports with general feedback from some stakeholders. Many in the field of water resources, but hydropower and wind energy producers were also present.
EUPORIAS	YES	FP7	Aim is to produce ready-to-use platforms with meaningful information for target companies, designed with feedback from the very end-users.
EWENT	NO	FP7	Scope of the project is forecast of extreme events and its impact on transportation and infrastructure. Interviews to rail transport experts have been made, but feedback is general at best.

INTACT	NO	FP7	Stakeholders on multiple critical infrastructures. Just one in the energy sector. No data on the interviews or workshops is available.
SPECS	YES	FP7	There is some preliminary information. Represents a reference in terms of capacity building.
CLARA	NO	H2020	Climate services, marketability and value for energy and other sectors Based on CCS. No information is available.
ClimateEurope	NO	H2020	Informal interaction with users in networking events. No systematic information available.
ESCAPE	NO	H2020	Highly technical, focused on enhance computing capabilities. No users involved in the available deliverables.
EU-MACS	NO	H2020	Twin project of MARCO. Focused on market analysis. Nothing on energy.
IMPREX	YES	H2020	Enhance forecast quality of extreme hydro-meteorological conditions and their impacts. User engagement at deliverable 8.3.
MARCO	YES	H2020	Explores the market for climate services in Europe. 2 out of 3 deliverables contain relevant information for the present document (D4.6 and D5.7).
PRIMAVERA	YES	H2020	Aims at providing high resolution global climate models. Deliverable 11.6 from WP11.
RESCCUE	NO	H2020	Focus in urban resilience. Users engaged are mainly researchers. Deliverable 5.4, with stakeholders' participation (some from energy sector) expected for M48, around 2020.
SECLI-FIRM	NO	H2020	To demonstrate how the use of improved climate forecasts can add practical and economic value to decision-making processes in both the energy and water sectors. No information made public at the moment of writing this deliverable.
STERCP	NO	H2020	No web portal has been found.

CLIM4ENERGY	YES	C3S	Found 6 deliverables with user information under WP2
ECEM	NO	C3S	Climate services and energy mix in Europe. There must be information on user engagement activities but it is unavailable.
SECTEUR	NO	C3S	To establish an inventory of existing policy needs and user requirements in terms of climate data and climate impact indicators. No energy users engaged.

Table 2: List of projects reviewed

Project name	Funding source	Users engaged	Techniques	Deliverables	References
ECLISE (2011-2014)	FP7	5 (D1.1) + 26 (D1.3)	Workshop (D1.1) + survey (D1.3)	D1.1; D1.3	Ludwig, F. and Weber, G. (2014) van Pelt, S. and Ludwig, F. (2014)
EUPORIAS (2011-2016)	FP7	14	Workshop + interviews + survey	D12.3	Dessai, S. and Bruno, M. (2015)
SPECS (2011-2016)	FP7	86	Workshops (7) with personal interviews	D61.2; D61.3	Lizcano, G. *et al* (2016) Davis, M., *et al.* (2015)
CLIM-RUN (2011-2014)	FP7	40	Workshops + personal interviews	D7.4	Schmidt *et al.* (2013)
CLIM4ENERGY (2015-2017)	C3S	6	Personal interviews	D1.1; D2.1; D3.1; D4.1a; D4.1b	Alternative energies and Atomic Energy Commission - CEA (2016)
MARCO (2016-2018)	H2020	>8	Workshops + survey + interview	D4.6; D5.5; D5.7	Tart, S. *et al.* (2018) Lisa, B. and Halsnæs, K. (2018) Lamich, K. *et al.* (not available yet)

PRIMAVERA (2015-2019)	H2020	15	Online survey + interviews	D11.6	Palin, E. *et al.* (2017)
IMPREX	H2020	11	Online survey + interviews	D8.3	Castelleti, A. *et al.* (2017)

1.2 Individual project revision

1.2.1 ECLISE

Enabling **CL**imate **I**nformation **S**ervices for **E**urope

URL: https://cordis.europa.eu/project/rcn/97417_en.html

ECLISE is an old project form FP7 introducing a new vision on climate services. From the very beginning (WP1) the project liaised with a diversity of stakeholders to understand the needs of the end-users and provide a meaningful service. Many of the feedback came from the water management sector, but some stakeholders from the energy system are also present (hydropower and wind power).

Deliverables with information on user needs:

- Deliverable 1.1 – summary of user needs.
- Deliverable 1.3 – user evaluation and best practices.

ECLISE metauser

The user is somewhat experienced on the use of climate predictions and is willing to incorporate seasonal forecasts in the decision-making process. However, users revealed a not complete understanding of the uncertainty associated to the models.

A consistent time series should be used to feed the models, with enough observational high quality data. The user needs are mostly focused on seasonal information about extreme events, but some predictions on average rainfall and wind speed would be used as well.

Users show interest in a systematic follow-up and trainings from the provider.

1.2.2 EUPORIAS

EUropean **P**rovision **O**f **R**egional **I**mpacts **A**ssessments on **S**easonal and Decadal Timescales

URL: http://euporias.eu/

The major goal of the EUPORIAS project was to demonstrate the usefulness of climate services to increase the resilience of European organizations at climate change. To accomplish this goal, a series of workshops, interviews and surveys were conducted on a wide variety of stakeholders, including a fair representation from the RE sector. The main outputs of the project were a series of prototypes providing seasonal forecasts, co-designed with the end users.

Deliverables with information on user needs:

- Deliverable 12.3 – Report summarizing users' needs for S2D predictions.

EUPORIAS metauser

The user is highly interested in climate information but the confidence on the current forecasts is low, especially on those with a lead time longer than a couple months. So far, short lead time weather forecasts from local meteorological services and historical climate data are being used in decision-making. Seasonal forecasts are used just as indicators or possible trends. No decadal projections are exploited.

The user, however, claims to be highly interested in forecasts of extreme weather events, potentially harmful for their assets. Most especially on high winds, floods, droughts, landslides and storm surges. These are events hardly anticipated using past climatology in a climate change background.

Whenever the user interacts with the available models and DST (preliminary versions), urges the developers to improve its accessibility and usability, for the sake of clarity. A relevant claim is the difficulty to make decisions based on probabilistic approaches.

1.2.3 SPECS

Seasonal-To-Decadal Climate **P**rediction for the Improvement of **E**uropean **C**limate **S**ervices

URL: http://www.specs-fp7.eu/

SPECS aimed to identify the main challenges in S2D (seasonal to decadal) prediction and illustrate a range of solutions from a seamless perspective, both in terms of time scale and between information producers and end-users. Thus, an important part of the project is the engagement of a variety of stakeholders, not just to provide feedback, but also to become an active part in the design of the outcomes.

Deliverables with information on user needs:

- Deliverable 61.2 – Recommendations to stakeholders on how the s2d forecast improvements from RT3, RT4 and RT5 could impact the prediction of crop yields including fact sheets and FAQs.
- Deliverable 61.3 – Information distributed under technical note 4: Barriers to using climate information: Challenges in communicating probabilistic forecasts to decision makers.

SPECS metauser

The user engaged under the SPECS project is somewhat interested in seasonal to decadal forecasts. However, the general awareness is low.

The user acknowledges some advantages of the mid-to-long range projections in terms of facilities' management, overall security of investments and spot price negotiation. Therefore, there is pronounced willingness to apply the tool for decision-making.

However, some issues concern the user, such as the low skill of the forecasts. This issue, combined with the general lack of expertise, makes it difficult for the user to rely completely on the information provided. So far, this information would be used just as an indicator.

The user has some comments on how to improve the display of the forecasts on the websites. Refer to the CLIM-RUN section for details.

1.2.4 CLIM-RUN

CLIMATE **L**OCAL **I**NFORMATION IN THE **M**EDITERRANEAN REGION **R**ESPONDING TO **U**SER **N**EEDS

URL: http://www.climrun.eu/

CLIM-RUN aimed at developing a protocol for applying new methodologies and improved modelling and downscaling tools for the provision of adequate climate information, at regional to local scale. The protocol should be relevant to and usable by different sectors of society (policymakers, industry, cities, etc.). Since CLIM-RUN was conceived with a true bottom-up strategy, it engaged with a diversity of stakeholders in the design of the climate services they would use in the future.

Several documents reporting the results of many workshops are available. Some of the stakeholders engaged represented the RE sector.

Deliverables with information on user needs:

- Deliverable 7.4 – Cross-cutting conclusions

CLIM-RUN metauser

The user is not an expert on climatology and the overall knowledge on climate predictions and modelling is low at best. Thus, the needs are expressed in very specific demands based on unrealistic expectations that cannot be fulfilled by current technologies. For instance, by requesting the exact expected amount of rain or temperature months in advance.

Uncertainty is a major downside of the models, making it impossible for the user to implement them into the decision-making processes. The risk is considered too high. Moreover, many banks and financial institutions demand projections based on historical records and will not accept climate prediction models to predict profitability and adapt annual loan fees.

The Decision Support Tools presented were far too complex for the user to fully understand all the information provided, so a bigger effort on clarity should be done. This must go in parallel with an even greater effort on communication directed to every possible stakeholder (a potential user) to help build the capacity to understand the forecasts and use it effectively.

1.2.5 CLIM4ENERGY

CLIMATE FOR **ENERGY**

URL: http://clim4energy.climate.copernicus.eu/

CLIM4ENERGY brought together the complementary expertise of seven climate research and service centers and nine energy practitioners to demonstrate, from case studies, the value chain from essential climate variables to actionable information in the energy sector. Under the CLIM4ENERGY project, an effort was made to identify the needs of different sectors on climate services.

Deliverables with information on user needs: D1.1; D2.1; D3.1; D4.1a; D4.1b

- Deliverable 1.1 – Wind power generation.
- Deliverable 2.1 – Hydropower generation.
- Deliverable 3.1 – Electricity generation-demand balance.
- Deliverable 4.1a – Freezing rain.
- Deliverable 4.1b – Bioenergy production conditions.

CLIM4ENERGY metauser

Clim4energy is targeted to a user with assets on the energy market, either physical or economic. Therefore, this user is especially interested in predicting anomalies from the average climatic record with potential impact on his/her activity. Generally speaking, the predicted indicators should prove skillful enough compared to other models available, and be operated on a user-defined time scale. Should an anomaly be predicted, an early alert has to be triggered and detailed information be provided, including the effects of similar events in the past.

Since the user has assets over the territory, s/he would use global indicators capable of being downscaled to the local level. At least the whole European region and its area of influence should be covered. A spatial resolution of 10 to 50km would be fine for seasonal forecasts, but 1km resolution is encouraged for sub-seasonal predictions.

The indicators should be updated at least daily or even hourly if possible. The user would need seasonal forecasts to be provided with a one-month lead time. The longest projections should extend ahead of time up to 2030 to 2050.

To assess the significance of the indicators, the user requires a measure of its uncertainty to be displayed along. This uncertainty should be calculated from a variety of sources, all fully accessible.

All the data, from the indicators to the forecasts and projections, should be available to download from a web or FTP-based service. Short reports in text format would be fine for human reading but large datasets should be provided in a standard machine-readable format instead. The user requires monthly reports with relevant statistics on extreme events distribution to be released as well.

The interface of the DST should be web-based, compatible across platforms and fully responsive for portable devices. The user prefers a fully customizable and interactive system, where all sources of information could be displayed together if necessary (text, graphics and maps). Clarity would be paramount, avoiding the use of potentially confusing terminology such as seasonal descriptions (like expressing seasons with months instead of words *summer/winter*).

1.2.6 MARCO

MArket **R**esearch for a **C**limate Services **O**bservatory

URL: http://marco-h2020.eu/

A number of barriers prevent the widespread uptake of the climate services market; however, the lack of appropriate services or technologies is not one of them. Some of the most common acknowledged barriers are market barriers and failures, financial barriers and institutional or administrative and structural barriers.

As a result, the current untapped market for climate services is very large and is characterized by both gaps between the supply and demand in the existing market and by a large latent market of demand and supply that is not realized. The MARCO project will characterize the current and untapped market for climate services in Europe and derive opportunities for market growth.

MARCO is focused on the general needs of a wide variety of stakeholders, from universities to large private companies. Some interviews with stakeholders from the Nordic market were conducted and information from the EUPORIAS project is also used as a reference. Only information regarding renewable energies has been used in the present digest.

Deliverables with information on user needs:

- Deliverable 4.6 – Segmented qualitative analysis of market demand & users' needs.
- Deliverable 5.5 – Case Study 4 Report: Wind & Solar Energy.
- Deliverable 5.7 – Case Study 6 Report: Critical Energy Infrastructures.

MARCO metauser

The user engaged under the MARCO project could benefit from all ranges of climatic forecasts, from short term sub-seasonal predictions to long term projections. However, despite there is some degree of usage, the services remain quite unknown and a greater effort on dissemination should be engaged.

One of the major barrier for the widespread use of forecast predictions based on modelling is the current models' lack of skill. Thus, user needs are focused on incrementing the reliability and accuracy of the predictions, most especially on extreme events regarding temperature, difficult to foresee using historical data in a context of climate change.

The lack of confidence on the services are so far tackled by retrieving information only from reputed sites, like well-known international services, and the use remains just as an indicator in the decision-making process. Providing a verified quality standard (ISO or DIN) for climate forecasts could help private companies and spin-offs get a share of the market.

One of the concerns the user finds is the uncertainty about the benefits of using these services. This uncertainty makes it difficult to assess whether the profits would be higher than the costs and, therefore, the willingness to pay for the services. This argument stresses the need for a better reliability and accuracy of the models and its communication.

1.2.7 PRIMAVERA

PRocess-based climate s**IM**ulation: **A**d**V**ances in high-resolution modelling and **E**uropean climate Risk **A**ssessment

URL: https://www.primavera-h2020.eu/

The PRIMAVERA project is aimed at providing high resolution climate modelling and risk assessment for various end-users, representing a diversity of fields: energy, insurance, transport, water management, agriculture and health. Only information of those involved on renewable energy production, consulting or trading will be included in the present summary.

Deliverables with information on user needs:

- Deliverable 11.6 – Report on end-user requirements.

PRIMAVERA metauser

The user engaged in the PRIMAVERA project would use short to long-time information for strategic planning, especially regarding the prediction of extreme events such as: high or low temperatures, possibility of ice formation, heavy or low rainfall, coastal hazards, high or low winds and lightning. Any of these events could, potentially, damage infrastructure, impair energy production or unbalance the supply. This user is fully aware of the climate change context and generally sees it as an opportunity to grow. However, the use of future climate data is seldom and based on past climatology.

Thus, the user would benefit from a modelling-based service providing information about when an anomaly is expected and its intensity and length. This information should be consistent, high quality and accurate (high skills) and be supported by renowned organizations.

The data should be easily available in multiple formats for compatibility issues. The cost of the service, if any, could be an important barrier for some applications.

1.2.8 IMPREX

IMproving **PR**edictions and management of hydrological **EX**tremes

URL: http://www.imprex.eu/

IMPREX is an H2020 funded project starting in 2015 and ending by 2019. Its main objective is to increase predictability of extreme hydrological events (floods and droughts), relevant for the activity of many economic sectors linked to the water supply, such as water basin management, river transport, hydropower production, agriculture and urban water management.

Deliverables with information on user needs:

- Deliverable D8.3 – Report on needs in hydropower sector.

IMPREX metauser

The User engaged by IMPREX is either an energy trader, a reservoir operator or a hydrologist (as defined by the project interviewers). It is a regular user of forecasting services, mostly on precipitation and temperature, and demands high temporal and spatial resolution: hourly for weather forecasts and daily for climate projections.

For short term the user relies on a forecast horizon of "a few days" (sic), while for climate projections the forecast horizon is for several months or seasons ahead. The range of actions the user takes based on forecasts is quite large, from daily operation to strategic planning.

In general, the user from IMPREX is highly interested Thus, the frequency of use of the prediction systems is largely depending on the action to be taken and may vary between several times a day, or once per season.in forecasting variables more relevant to the particular activities of the sector, such as streamflow, energy prices or flood probability. The demands concern the improvement of forecasts for streamflow, weather extremes and longer lead times.

The analysis of current use and future demands shows a good adaptation of the user to the actual services offered and a fair integration of the forecast technologies to the user's decision-making.

1.3 Generalised energy sector metauser

The typical S2S4E target users are renewable energy (RE) power producers, energy wholesale traders or transmission systems operators. The main motivations to use seasonal forecasts are economic-based – improve the facilities' management and secure profits and investments – and public service-related, as long as they deal with a basic consumer good.

The users are mostly, but not completely, aware of the benefits of seasonal forecasts for their companies. In fact, they are already using weather information in their decision-making processes, mostly historical climate data or short lead-time meteorological forecasts. When they peek into longer lead-time predictions, it is only from highly reputable sources and just to be used as an indicator.

The downside of the described use is that short lead-time forecasts do not allow for long-time planning and historical data cannot predict future trends and climate variability in a context of climate change. Hence, the use of seasonal forecasts based on high performance simulations would really make a difference.

However, the available outputs of climate predictions are not attractive to the RE sector due to several shortcomings, summarized in its complexity, low accuracy and reliability (skill), especially when considering longer lead-times. This is a major issue, since low confidence in the models mean they will not be used to make strategic decisions, one of the goals of S2S4E.

When asked to participate in the co-design of an S2S service, the users were mostly interested in high resolution Europe-wide seasonal and sub-seasonal information, particularly on extreme events. Situations like high or low winds, heavy or little rainfall, flood, landslide or drought risk, storm surges with heavy lightning, ice formation or coastal hazards are the most demanded. Information on the length and intensity of these anomalies, with at least one-month lead-time, would be helpful not just to predict energy production and consumption, but also to protect the assets from potential hazards.

Despite of the current lack of usability, a fair effort has been made to imagine a platform for future decision-making. The users engaged consider the quality and availability of the data a must, and urge to comply with the ISO or DIN international standards. Timely statistics (monthly or weekly) on extreme events should be provided and all the outputs have to be easily downloadable. The datasets must be offered in several formats, such as human and machine-readable, from reputed institutions. The service should be offered at low cost, or even at no cost, due to the EC funded nature of the projects. Some users would show willingness to pay if there is a good product paired with expert advice.

The preferred platform is a web service, fully accessible, customizable, compatible across platforms and responsive to mobile devices. Both content and display would have to be clear and intuitive, avoiding confusing terminology. On this regard, a comprehensive support section into the website would be welcomed, along with the possibility to be trained in-house by the service providers.

1.4 Final remarks

The revision of the projects above and their metauser description, provides an overview of how user engagement in the climate services field has evolved from a wider engagement with stakeholders in the FP7 projects (back in 2011) to a more focused interaction in a one-to-one basis such as the one in Clim4Energy or S2S4E.

In the first stages of user engagement (e.g., ECLISE, CLIM-RUN) most of the dissemination and engagement actions aimed at calling the attention of potential stakeholders to the field of climate services and communicating the objective of climate predictions and their time scales, differentiating them from the widely known and used weather forecasts and climate projections.

The following projects (e.g., EUPORIAS, SPECS) and interactions were able to obtain a deeper understanding in user needs and to explain the technical aspects of climate predictions with more detail. Users engaged in the projects were more acquainted with the concept of climate predictions and their time scales. There was a better understanding of the capabilities and limitations of the climate models and what climate services can or cannot provide to cover the information needs of energy users regarding daily operational decision-making. However, users still saw climate predictions too far away from their decision-making processes and it was difficult to imagine how to integrate them.

After a continued interaction with the climate services community, some of these users become user champions themselves. These type of users learn enough about the topic to be involved in the projects (e.g., IMPREX, CLIM4ENERGY) as a sparring partner to provide more detailed feedback. They are more open to use or test the services but they also spread the word about the services among other users not reached by the research community. The integration of the users in projects helps researchers to develop proofs of concept of climate services (operational or semi-operational) that try to fill the users' informational needs.

This user evolution illustrates how sustained user engagement over different and not necessarily interconnected projects has built capacity on the energy users and has created bonds that facilitate the creation of consortia with the primary goal of co-creating a usable climate service for energy.

It is also remarkable that the initial prototypes (e.g., CLIM-RUN) had a more static case study setting with description and analysis of the potential of climate predictions in a sector. After those, and following the concept of User Interface Platform described in the Roadmap for climate services report (EC 2015), there has been a progressive evolution towards more concrete prototypes such as the ones in EUPORIAS, to finally evolve into web based platforms providing information co-designed with users (Copernicus C3S Sectoral Information Systems examples).

Chapter 2
In-depth interviews

2 In-depth interviews

After the revision of the existing knowledge gathered from previous projects (in chapter 1), this second chapter focuses on in-depth interviews conducted within the S2S4E project. The main objective of the interviews was to collect information about whether and how S2S forecast information is or can be used to make better decisions (e.g., economic, operational) in companies in the energy sector, increasing their profits.

In-depth interviews were chosen - instead of other approaches such as surveys - because they allow for flexible, detailed and bilateral or multilateral (for those involving a group of respondents) conversations between interviewers and respondents/interviewees. Direct interactions easily allow perceiving which are key issues/interests of the users and shape the conversations case by case and learning the most out of them. While common objectives in terms of what information to gather were set in advance (resulting in interview guidelines), the interviewers were driving the conversation to the topics where each of the users were able to give greater contribution, letting the conversation flow. This would not have been possible with a survey that has a lower degree of flexibility and it is unidirectional, not allowing for a real conversation and for the simultaneous interaction with a group of users. Moreover, in-depth interviews are a powerful way to engage with users by having a bilateral conversation when users can also ask for questions and raise their own interests.

Through the interviews we were able to map current use of S2S information, explore real-life decision-making contexts and situations where S2S forecasts could be usable, identify knowledge gaps, and encourage interviewees to figure out how S2S forecast information can be adapted into and be made relevant to their decision-making systems. In this chapter we start by describing the methodology (preparation and way of conducting the interviews as well as the choice of the sample). Subsequently the results of the interviews regarding user needs and decision-making processes are presented. Finally, four new case studies of interest for users identified during the interviews are described. This was a necessary step from Task 2.2 linked to WP4. Task 4.1. will use these four case studies and the four previously defined in the proposal to provide an assessment of the forecasts capability to reproduce the observed anomalies and their impact on the relevant energy indicators.

Finally, it is worth to recall that this report presents all comments and requests from interviewees. These are user needs in a broad sense, but not all suggestions and requests can be implemented. Some are too user-specific, others are not technically feasible or they do not fit with the DST purpose and target user. The recurrent interaction between scientists and potential users in WP2 and WP5 will be very important to align expectations.

2.1 Methodology
2.2 Interviews results

2.1 Methodology

2.1.1 Sample size and organisation

We conducted **8** in-depth interviews (in 8 different companies), from which 5 were group interviews with 2 to 4 persons in each and 3 were interviews with 1 expert respondent. For each interview the members of the group were selected, when possible, with different backgrounds and functions in the company. In total 18 people from 14 different departments were interviewed. However, they all have in common that they currently use and/or consider using information on S2S time scales in decisions related to the company's operations, finances or investments. Operational decisions might be related for instance to energy generation or maintenance; financial decisions might be related to energy trading; and investment decisions might be related to internal adoption of new technologies or financial investments in the renewable sector.

The interviews lasted about 1.5 hours, in some cases up to 2 hours. Table 4 lists the interviews performed and the respective respondent's profile together with the department and organization's type they are working for. The interviews involved energy providers, producers, transmission system operators (TSOs), distribution system operators (DSOs) and an in-house weather data provider of the DSO.

A comprehensive geographical coverage was guaranteed by the choice of interviewees working in different countries: France, Germany, Norway, Spain, Sweden and United States.

Table 3: Overall figures

	Interviews	Organizations/Companies	Departments	Respondents	Countries
Total	8	8	14	18	6

Table 4: List of interviews

Interview #	Organization/company's type	Department	Respondent's type
1	Energy Producer	Optimisation (Resource Assessment)	R1: Methods and tools Expert
2		R&D (Resource Assessment/in-house weather data provider)	R2: Meteorologist/Climate Analyst

3	Energy Provider	Operation and Maintenance (O&M)	R3: O&M manager
		Corp-Energy Assessment (Resource Assessment)	R4: Meteorologist/Climate Analyst
		Department of Management, Market Operations Unit (Trade)	R5: Trader
		Market Operations (Trade)	R6: Trader
4	Energy Producer and Provider	Support trading decisions (Trade)	R7: (Senior) Meteorologist
		Support trading decisions (Trade)	R8: (Senior) Meteorologist
		Power Market (Resource Assessment)	R9: Meteorologist
		Power market (Trade)	R10: (Senior) Trader
5	DSO	Grid Planning	R11: Member of Technical Direction
6	TSO	Models and Predictions (Resource Assessment)	R12: Meteorologist/Climate Analyst
		Models and Predictions (Resource Assessment)	R13: Meteorologist/Climate Analyst
		Models and Predictions (Resource Assessment)	R14: Meteorologist/Climate Analyst
7	Energy Producer and Provider	Hydrology and Climate	R15: Hydrologist (PhD)
		Trade (Market division, Financial optimization and hedging)	R16: Hydrologist (PhD), now working as a Trader
8	Energy Producer and Provider + Water management company	Hydropower optimization, planning and selling hydropower production (Resource Assessment)	R17: Hydrologist
		Forecasting service (Resource Assessment)	R18: Hydrologist

2.1.2 Specific terminology

In the conversations with interviewees, the term weather is sometimes used as equivalent to climate, not in line with the scientific definition. For better understanding in this report, we have adjusted the words weather and climate following the criteria of **Error! Not a valid bookmark self-reference.**.

Interviewees sometimes refer to weather parameters, variables or climate variables. In climate science, the correct term would be Essential Climate Variables (ECV), a term used over the S2S4E project. For consistency over the report and to keep the text simple and aligned with user's terminology we have used the term climate variables.

Table 5: Weather forecasts and climate predictions

	Weather Forecast		Climate Predictions
Time horizon	10 min – 15 days		1 week – 7 months
Time resolution	1 hour (5 min if needed)		Weeks, months, seasons
Horizontal resolution	m^2 – few km^2		About 100 km^2
Definition according to ECMWF	Short term (Max 3-5 days)	Medium term (Up to 15 days)	Long range

S2S4E project

2.1.3 Interview guide narrative and structure

The narrative of the interview guide was the following:

- Status quo: How (if at all) do the end users currently use S2S information, and in what sort of decisions?
- What (if applicable) do the users currently find most useful (or not) about S2S information?
- Which aspects of future climate make it difficult to make certain decisions «today»?
- Do the users miss some information for making better decisions?
- In that case, what information do the users want/need for what decisions?
- How can that information be provided?
- How can we make sure the information is usable?

More specifically, the interview guide and its questions were structured along three main lines or topics:

- **TOPIC 1:** Current use of climate and weather information (particularly sub-seasonal to seasonal (S2S) forecasts) in what types of decisions (e.g., economic, operational, financial) regarding renewable energy production, energy trading, electricity demand management, etc.

- **TOPIC 2:** Identify decision-making processes, situations and types of decisions where S2S information could be useful (both real-life and ideally), and uncover how different types of uncertainty plays into and is managed in decision-making.

  Detect what information (specifically having probabilistic S2S real-time forecasts in mind) with what attributes (e.g., level of certainty, skill) could help optimizing operations/decisions, both generally or in extreme events.

- **TOPIC 3:** Explore how that information can be adapted to be relevant to their specific decision-making contexts and current decision-making tools (having the S2S4E Decision Support Tool in mind). Reflect upon how to facilitate increased uptake of S2S information in decision-making, and how the performance of the DST can be assessed in real life decision-making.

For the detailed list of questions please refer to the interview guide in Appendix I.

It is worth noticing that despite having an interview guide with all the questions, the interviewers approached the interviewees in a quite open-ended manner, and let the topics listed above guide the discussion, rather than following the list of the questions literally. This approach allowed for a natural flow of the conversation and facilitated the interviewees in responding.

2.1.4 Ethical considerations and GDPR

Before starting the interview, all interviewees were informed about the project and its main objectives. After this presentation the interviewees were informed about their personal data would be stored safely in line with the EU regulations (GDPR) and then they were handed an Informed Consent form to sign. The interviewees were also asked for their oral consent to record the interview.

The identity and information obtained in the interviews has been anonymized in the reports and reported at an aggregated scale so that the information cannot be traced back to a single interviewee/company.

In order to collect properly the personal data during the interview we have followed the guidance published in *D8.1 POPD - Requirement No. 1: Information sheet for users*, and *D8.2*

POPD - Requirement No.2: Guideline for personal data management and used in Informed Consent form available in D8.1 and in Appendix II- Consent form

2.2 In-depth interviews results

2.2.1 Weather and climate information: current use (TOPIC 1)

This section focuses on establishing the current state of knowledge of the users in the energy sector. To achieve this, seven questions were set and responses were analysed about the following aspects:

a. Most important weather and climate conditions;
b. Most relevant aspects of each weather and climate condition;
c. Weather and climate information/datasets;
d. Record/register/analyses of historical impacts of weather and climate on organization's operations;
e. Forecasting tools;
f. Current use of S2S forecast information.

a. ***Most important weather and climate conditions***

All respondents highlighted that they are currently using or in need of weather and climate forecasts. Out of the 8 interviews, (mostly) all showed interest on information on temperature and precipitation (see Figure 1a). Wind speed and solar radiation are also important for most respondents focusing on wind, solar and demand, it had lower importance for the hydropower sector. In addition to these variables, the analysis indicated an additional list of variables of interest (Figure 1b). However, these were very specific to each user and its needs.

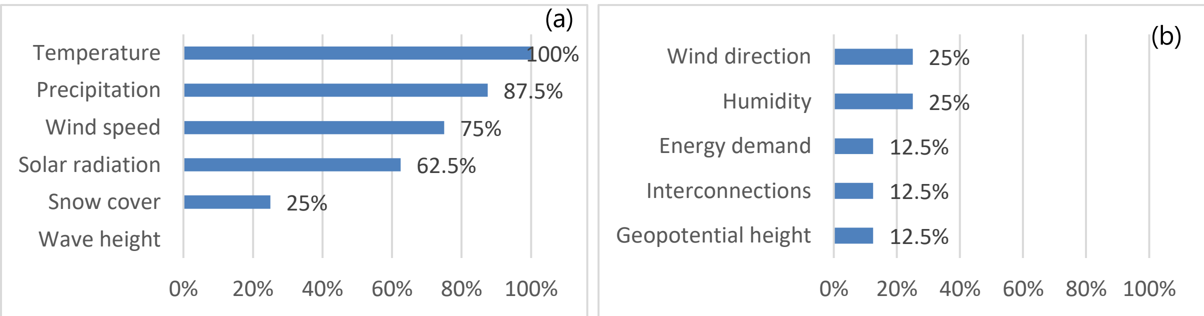

Figure 1: (a) Responses on key weather/climate variables, (b) additional weather/climate conditions defined by interviewees. Respondents taking part in the same interview (and organisation) unanimously agreed and count as one response.

b. ***Most relevant aspects of each weather and climate condition***

Meteorological forecasts from the climate models can be provided at a fine temporal resolution (i.e. hourly), however the time resolution needed varied between the interviewees and for the same interviewee depending on the context (Figure 2a). The hourly temporal resolution of the forecasts is the most required (as revealed by 60% of the comments on the topic), whilst forecasts at 3-hour and daily temporal resolutions represent 20% of the needs each.

Although the respondents require data at daily or sub-daily resolution, they use this information to create forecasts at coarser temporal resolution (Figure 2b). The interviewees make decisions for the future by analysing forecasts at weekly, bi-weekly, monthly, seasonal and annual aggregating windows. This means that decision-making is dependent on both sub-seasonal and seasonal forecasts. Interestingly, the interviewees here show similar interest to all these temporally aggregated windows, with the exception of bi-weekly aggregation that seems to be less requested.

Regarding the geographic resolution or aggregation level at which decisions are taken, the interviewees responded that they are interested in local, regional and national scales, with the two latter being the most requested ones (Figure 2c).

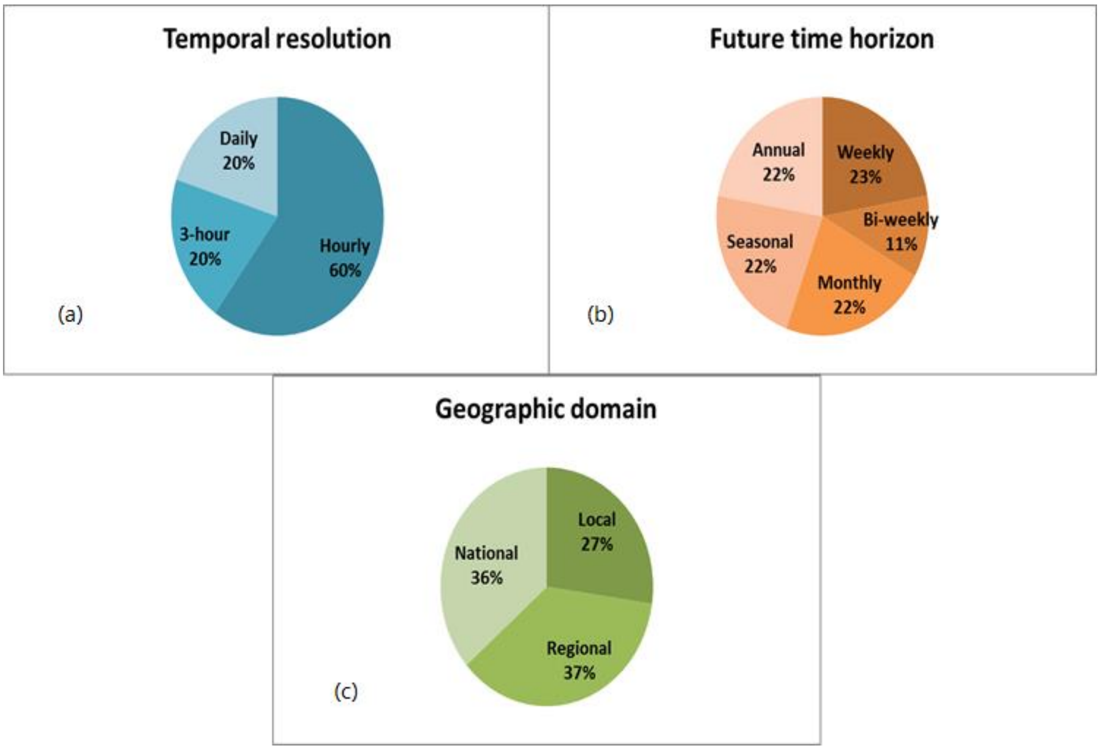

Figure 2: Respondents' needs on forecast information with respect to: (a) temporal resolution, (b) future time horizon, and (c) geographic domain. Percentage of total responses.

c. ***Weather and climate information/datasets***

The interviewees are currently provided with forecasts from different centres (Figure 3a). The most popular data provider (70%) is ECMWF, followed by GFS with 20%. The users are interested in both raw and post-processed information; with a significant proportion of cases where post-processing is used (about 63%; Figure 3b). When processing is needed for enhancing decision-making, this is usually conducted by the interviewees (Figure 3c); this is a group of users known as knowledge purveyors, which have the knowledge and understanding on how forecast information can be extracted by post-processing. Finally, in one third of the cases, users acquire the forecasts for free (33%), whilst most of the times they need to pay for these services (Figure 3d).

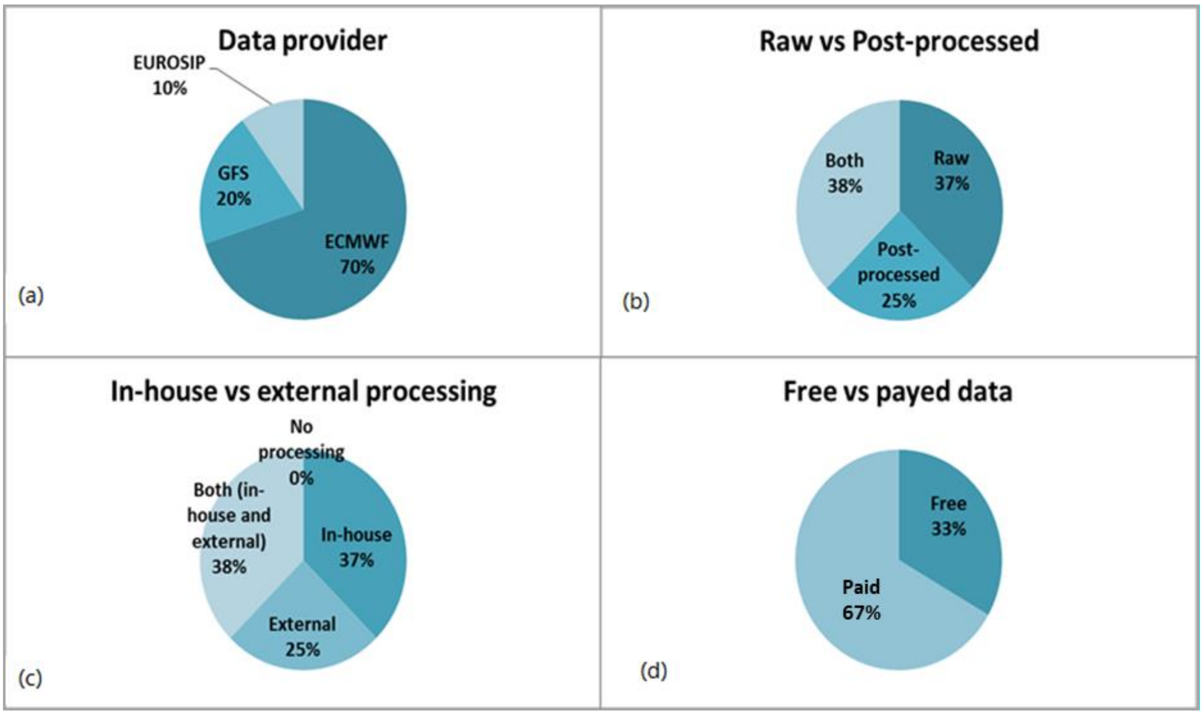

Figure 3: Characteristics of forecast data in terms of: (a) data providers, (b) data purpose, (c) processing of data, and (d) data as business service. Percentage of total responses.

d. ***Record/register/analyse historical impacts of weather and climate on organization's operations***

The practice of storing and/or analysing the historical weather and climate based impacts varies case by case. In 40% of the cases, interviewed users are recording historical events with a significant impact, whilst 60% of the interviewees declared that they analyse those for better understanding (Figure 4a). The analysis aims to indicate whether past decisions were compliant with regulation and/or to assess the economic impact of previous events (Figure 4b).

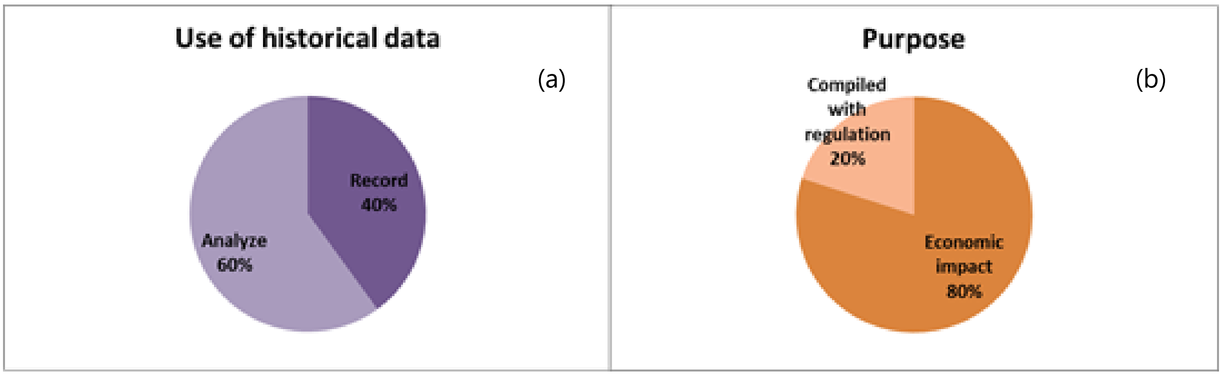

Figure 4: Interviewees' needs to have access to historical information for: (a) recording or analysis, (b) assessment of historical events. Percentage of total responses.

e. ***Forecasting tools***

In general, the interviewees are in need of forecasting tools, which are provided from various sources; Only one user reported not using any forecasting tool (Figure 5). Most interviewees apply tools from national, regional or consultant forecast providers (stated as 'Others'). However, quite many also use tools from ECMWF and Meteo-France. Note that the popularity of ECMWF and Meteo-France is not related to the reliability of their forecasting tools, but it is rather a matter of regional interest from the interviwees besides the effect of having easy access and availability of the data. In addition, GFS tools are also popular, whilst many respondents are applying tools developed in-house (stated as 'Internal').

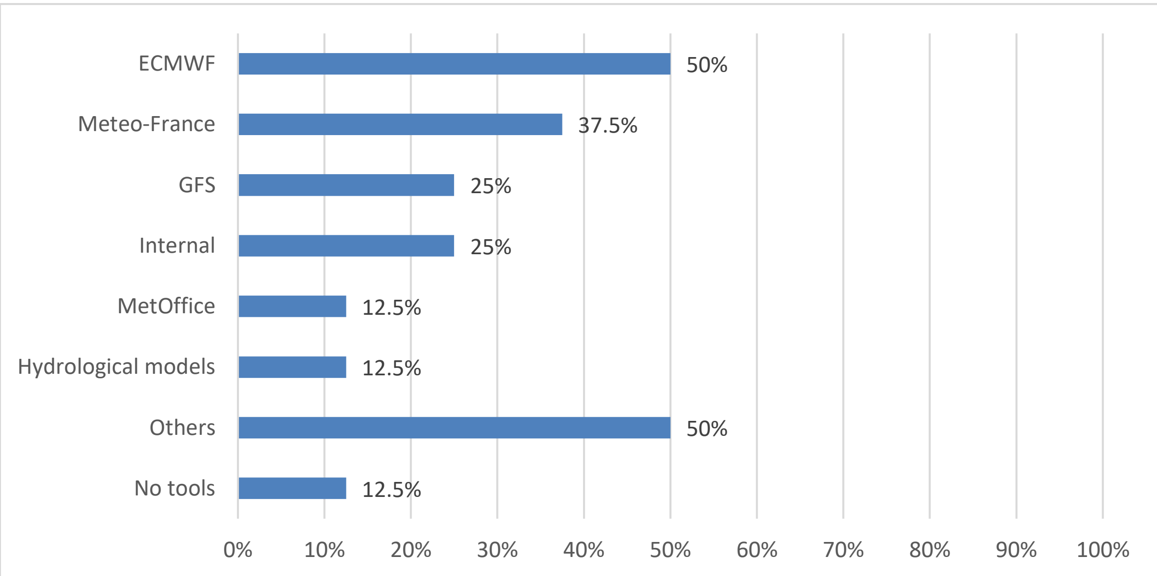

Figure 5: Weather and climate forecasting tools from different providers. Respondents taking part in the same interview (and organization) unanimously agreed, and count as one response.

f. ***Current use of S2S forecast information***

In half of the interviews, the respondents declared that currently there is no use of S2S forecast information for any decision while the other half explained that they are already using it for one or more applications. The current application of the S2S forecasts is summarised in Figure 6. All the interviewees that are using S2S forecasts (in 4 out of 8 companies interviewed) are applying them in decision support tools to run operations/services (in the time horizons described earlier). Some of them also exploit S2S forecasts for risk management (2 out of 8) and market decisions (1 out of 8). None of the respondents is making maintenance decisions based on S2S information. Noticeably, among the interviewees that are not currently using S2S forecasts there is an emerging interest in the potential applications. In fact, in the interview number 3 (see details in Table 4) respondents declared that their organization is undertaking trials and others are approaching qualitatively the information. The reasons that may refrain these users in the uptake of S2S forecasts are analysed in the following sections.

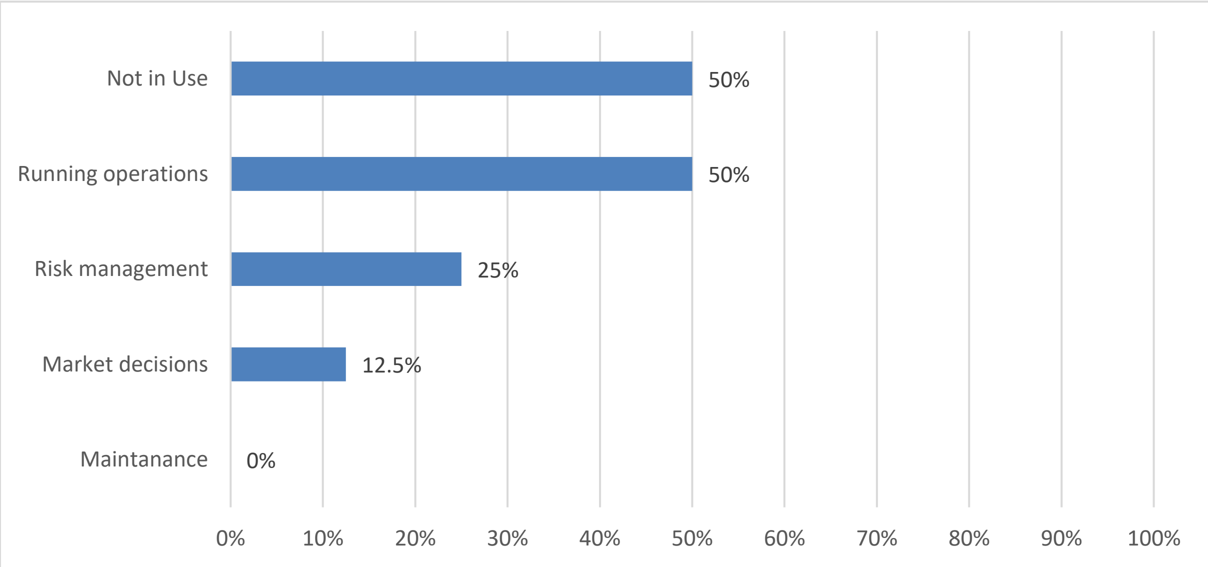

Figure 6: Current usage of S2S forecast information.

2.2.2 Decision-making and risk management (TOPIC 2)

2.2.2.1 Decision-making processes

This section focuses on weather and climate dependent decisions. It aims at understanding to what extent decisions depend on weather/climate conditions and describing energy stakeholders' current way of working and use of weather/climate information. To that end, this section is structured as follows:

a. Weather and climate dependent decision: General findings
b. Categories of weather and climate dependent decisions
c. Time scale of weather and climate dependent decisions
d. Critical metrics and associated weather parameters
e. Way of working
f. Current deficiencies and needs of improvement

Given the relevance and variety of decision-making processes, further analysis of this section has been conducted resulting in Decision Maps of weather and climate dependent decisions available in section 2.3.

a. Weather and climate dependent decisions: General findings

The cross-analysis of all interview results highlighted the wide dependence of the energy sector on weather and climate information. Interviewees confirmed that all steps of the electricity value chain (from the production to retail activities, including the transmission and distribution) are impacted by weather conditions. Furthermore, this dependency concerns all departments within a single company. Whether interviewees deal with financial, operational or contractual decisions, they all consider weather and climate conditions in some of the most important decisions they make on a regular basis.

All these important decisions have in common that they are weather- or climate-dependent despite the decisions do not necessarily have the same goal. They may be made to ensure the supply to customers, guarantee the safety of workers or citizens living in the surrounding of the infrastructures, limit the impact on the environment or secure legal contract for instance. However, a large majority of the decisions mentioned during the interviews have an economic aim, whether it is optimising profits or limiting losses.

b. Categories of weather and climate dependent decisions

This section explains the different categories of decisions, the importance of weather or climate information for such decisions and the actors involved.

Table 6 summarises the information collected in the interviews concerning the different category and types of decision and the Essential Climate Variables (ECV) used in each case.

Table 6: Category, types of decision and climate variables

Type of decision	Category of decision	Stakeholder	Climate variables
Safety & Prevention measures	Operation	All types of stakeholders	Wind speed Level of water in reservoirs Precipitation Snow cover
Maintenance planning (Including predictive maintenance)	Maintenance	All types of stakeholders	Temperature Precipitation Wind speed Solar radiation
Compensation of distribution losses	Financial	DSO	Temperature Precipitation Wind speed Solar radiation
Trading and hedging	Financial	Energy producer & provider	Temperature Precipitation Wind speed Solar radiation Humidity
Production planning	Operation	Energy producer & provider	Temperature Precipitation Geopotential Wind speed Solar radiation Level of water in reservoirs
Water resource management	Operation	Energy producer & provider	Level of water in reservoirs Precipitation Snow cover and depth
Network planning	Operation	DSO/TSO	Temperature Precipitation Wind speed Solar radiation
Management of the transmission bill	Operation	DSO	Temperature Precipitation Wind speed Solar radiation Humidity
Blackout prevention measures	Operation/ Maintenance	TSO	Precipitation Wind speed

<u>Operational decisions</u>

According to the interviews, all types of stakeholders have weather-dependent decisions to make as part of their operational activities.

Interviewees talked about the use of weather data for safety and prevention matters within operation activities. As an illustration, hydropower producers noted that forecasts are used to optimize the enforcement of the regulation considering environmental safety (flooding) and structural dam safety. Similarly, wind power producers observe a wind speed limit for safety reasons.

All stakeholders targeted for this research declared to make use of weather information for operations planning. In an interview with optimisation experts, attention was drawn to the usefulness of weather data for deciding whether to run plants and scheduling maintenance of wind and hydropower plants.

Weather and climate data is of crucial relevance for energy producer and providers, who are frequently running predictive models to estimate the energy production potential for the different means of production. Moreover, interviewees emphasized the use of climate data in face of extreme weather events to estimate impacts on energy production capacity.

Both DSO and TSOs also agreed on the value of climate data for network operations. Climate data is used for transmission planning, management of operations and contractual obligations and repairing activities.

However, some operational decisions are specific to the type of stakeholder. For instance, energy producers and providers that operate hydropower plants are concerned about water resources management in dams. During the interviews, hydropower producers talked about the use of hydro-meteorological information for deciding whether to conserve and store water in dams for some periods instead of producing energy.

On the other hand, the interviewed TSO experts highlighted the use of weather and climate information to prevent blackouts caused by extreme weather events. For this reason, short-term (weather) and sub-seasonal and seasonal information about extreme conditions is ranked as highly important to avoid severe economic losses. For instance, a blackout has an elevated economic impact and taking prevention measures to avoid blackouts often turns out to be less costly.

Maintenance decisions

All stakeholders have a department dedicated to the maintenance planning. Maintenance activities highly depend on weather conditions.

It can be concluded from the interviews that maintenance is planned according to energy production activities. Weather data is used to avoid problems in the balance between the demand and the supply when stopping production to carry out maintenance.

In a similar manner, according to the interviewees, TSO and DSO take into account weather conditions before performing maintenance. For instance, maintenance is not planned when storms or other extreme weather events are expected.

In addition, an energy transmission expert talked about the use of climate data for planning predictive maintenance in order to adapt and prepare for the impacts of extreme weather events. As understood from this interview, the idea behind predictive maintenance is to boost infrastructure resilience and reliability to ensure energy services provision even under extreme weather.

Financial decisions

Financial decisions mainly concern energy producers and providers, who participate in the financial transactions carried out in the energy exchange markets.

Energy producers and providers rely on weather and climate data for financial decisions, concretely short-term and long-term trading. Three out of the six energy producers and providers interviewed, mentioned that weather and climate forecasts and historical data is used for trading decisions, for deciding when is a good moment to purchase or to sell electricity in the market.

Likewise, according to the DSO representative interviewed for this research, weather data is also used to support decisions related to the compensation of distribution losses. The financial department, responsible for this activity, has to evaluate losses induced by the Joule effect all along distribution cables and purchase on the market the necessary energy to compensate these losses.

Contractual decisions

Contractual decisions concern energy producers and providers and DSO and TSO in different ways. The different usages of weather and climate data for contractual decisions are illustrated in the examples that follow.

As explained in the interview with a DSO expert, the management of the electricity transmission bill relies on weather data for two reasons: On the one hand, it needs to estimate the consumption which is highly thermo-sensitive. On the other hand, decentralised local production is becoming more and more widespread (photovoltaic, wind and hydropower). Therefore, DSO's need to estimate production from renewable sources to calculate from where energy will be produced and distributed to ensure the demand is met efficiently.

By contrast, one of the energy producer interviewed noted that historical climate data is also used for defining energy long-term deals' terms and conditions.

The types of decisions are analysed in detail with ad-hoc Decision Maps of weather and climate dependent decisions in section 2.3.

c. *Time scale of weather and climate dependent decisions*

The time scale of decisions indicates for how long a decision will be binding for the company, before they can redo and adapt to changes. Some decisions are fully binding over a given period, while others may be partly binding, so there is not always an exact answer to this. The time scales of decisions relate to the different activities across companies but also within companies, meaning that the answers to the questions reflect the role that interviewees have within the company. Table 7**Error! Reference source not found.** shows the typical time scales for the core decisions mentioned during the interviews.

Table 7: Time scale per core decision

Category of Decision	Sub-aspect	Typical time scale
Financial	Energy contracts, hedging	One month to one year
	Trading	Hours to several months
Maintenance	Hydro reservoirs	One year
	Solar and wind	Months
Operations	Regulation of water basins	One year and more

The decisions that were identified as dependent on climate in the coming seasons can be classified as decisions related to the financial results for the companies, to maintenance, and to the planning of reservoir filling in water magazines in hydropower plants. To the commercial companies, all decisions, including maintenance and reservoir filling, aim at contributing to the financial result. Different time scales matter in this respect. Many decisions related to the operation of the companies, such as maintenance and reservoir filling, depend heavily on expectations on weather and climate conditions. These constitute only a part of the financial concerns, which in addition depends on weather and climate conditions related to the demand for energy and the supply of electricity from other companies. Companies operating in spot markets decide on their level of production depending on their expectations of market prices in near future, down to an hourly basis. Other parts of the production may be sold by long-term contracts, which are based on expectations about the development of market prices and operating costs over the coming months and year.

Maintenance requires that production is reduced or stopped for a period, with no income. It should therefore take place when incomes are expected to be low. The losses also depend on the length of maintenance period, which differ considerably depending on the energy sources. Solar and wind plants need maintenance more often, but it can be planned and carried out with a much shorter time perspective, and should take place when combinations of production possibilities and prices are expected to be low.

Operations such as management of reservoirs in hydropower plants implies particular challenges that depends heavily on precipitation, temperature, and snowmelt. The filling of reservoirs give companies a flexibility to adjust the production on an hourly basis, which is impossible for the plants based on other energy sources, some exception for coal plants. However, the flexibility in hydropower plants decreases the less water there is in the reservoirs. The companies therefore have to avoid constraints due to low level of filling when prices are high. At certain critical levels, public authorities may impose constraints for security reasons, which means that the production is more or less fixed. There are also public institutions with responsibility for the management of entire water basins or larger areas with more than one hydropower plant. Their attention is on the allocation of water supply across plants to ensure that the benefits of water basins are allocated in a way that the benefits from the entire area are exploited. Reservoirs are filled more or less regularly on a seasonal basis, following expected patterns of precipitation and snowmelt, which may vary from year to year. Hence, the planning period is at least one year.

d. ***Critical metrics and associated climate variables***

Consumption rate (temperature)

Temperature is the most used climate variable, according to the aggregated responses of all interviewees (confirming the results obtained while investigating about the current use of weather conditions in general – section 2.2.1). This finding comes as no surprise, as temperature is the main parameter used to forecast the electricity demand, the energy metric that is monitored in most, if not all, weather dependent decisions. Indeed, traders would not perform any sale or purchase operation on energy markets without ensuring first that the estimated level of production will match the demand. Similarly, the activation or shutdown of a power plant would not be decided without considering the electricity consumption.

The level of interest in the temperature may vary from one country to another though. The thermo-sensitivity of the electric demand has a strong influence on the importance of this variable. Thus, stakeholders from France, a country that has a significant part of its heating system that is electricity-based, particularly insisted on the use of temperature forecasts.

A few interviewees also mentioned their interest in relative humidity, another parameter used to estimate the demand.

Production from renewable sources (precipitations, wind and solar radiation)

Other climate variables named during the interviews are linked to the estimation of the electricity production. Although they were less mentioned than the temperature, it does not necessarily mean that they are less important. While the temperature has an impact on the electricity demand of all EU countries, the climate dependency of the electricity production depends on the composition of the energy mix.

Considering only the countries of origin of the interviewees -namely Germany, Norway, France, Sweden, Spain and USA- precipitations together with hydro-meteorological information are the most used climate variables to estimate the production. This fact is mainly due to the importance of the hydropower in the first four countries. The wind speed is the second most interesting variable, followed by the solar radiation, respectively to forecast the wind power and solar power production.

Two interviewees also mentioned their interest in snow depth, explaining that the initial states is of particular importance for its hydrological forecasts, notably at areas where snow melting has a significant impact on the calculation of water volumes. Another one declared using the geopotential height with an analogue method to predict precipitations at a basin scale.

e. *Way of working*

This section is dedicated to some specificities of the application of weather information in the decision-making process within the energy sector. Based on the results of the interviews, it intends to explain in more details the type of models that make use of weather data, the update frequency of forecasts, the general analytical process and the existing thresholds.

Type of models used

From the interviews carried out for this deliverable, different type models for specific aims were identified as supportive of internal decision-making processes. Interviewees refer to three types of models that are currently being used when making specific decisions that rely on weather data:

- **Models to forecast energy production and consumption:** Interviewees broadly mentioned the use of internal and external models to predict energy production and consumption. As an illustration, R1 uses Météo France models (ARPEGE, AROME, etc.) and ECMWF climate models outputs as an input for its internal model (developed R&D

department) to forecast energy production and consumption. For detailed information about the usage of different tools see section 2.2.1 (f).

- **Models to forecast energy prices:** Since energy prices frequently oscillate according to supply and demand variations, most of the interviewees notified the use of models to predict energy market prices. Some hydrologists interviewed, for example, mentioned the use of a price model that is filled with information and inputs from hydrological and meteorological models.
- **Optimisation models for operations:** Models that integrate data on energy production, consumption and prices are used for the optimisation of power plants operations. Those models support power plant operators minimizing costs and optimising gains from operations.

Model interdependency

What becomes clear from the interviews is that there is an intrinsic analytical process that establishes an order of usage for the different models and data. Generally, energy production and consumption models are used at the beginning of the process. Then, the output of those models feed information into energy price models. Lastly, energy production, consumption and price forecast information is integrated into optimisation models. As a case in point, R11 uses the output of the energy production and consumption models as an input for a deterministic algorithm that provides the optimal level of subscription assisting in the management of the electricity bill.

Use of weather data: quantitative or qualitative?

It has been noted that weather data is often used quantitatively in the models. However, S2S information is used only qualitatively by decision makers. The optimisation department (R1), for example, receive monthly seasonal forecasts per email (graphic figures, A4 format) sent by the R&D department. These forecasts are not used in the models but used qualitatively by the decision-makers of the Respondent 1. Actually, it has rarely happened that decisions were solely based on these forecasts. Often S2S information is used as supportive information of quantitative data.

Critical thresholds

Most interviewees do not know what the best way would be to provide information between a range of values for selected variables or the probability of certain events. However, they indicated key thresholds that are used to guide their decision-making process:

- **Wind power**: For wind power production, the upper threshold of wind speed is 20m/s. If the wind speed exceeds this threshold turbines must be stopped for safety reasons;

- **Hydropower**: operators of hydropower plants get notifications when the wind speed becomes higher than the same threshold (20 m/s). It is mainly for safety reasons when water levels in reservoirs are high;
- **Hydropower**: snow melting is important for the calculation of water volumes during the spring season. Therefore, the beginning of the snow melting is an interesting threshold for the water management in dam reservoirs;
- **Demand**: the temperature above which a building does not need heating is an interesting threshold due to the dependence of the electricity demand on the temperature. However, it was specified that this threshold was not specifically monitored but used in models forecasting the demand;

Interviewees mentioned another critical threshold that is indirectly related to weather and climate conditions:

- **Hydropower**: stakeholders of the hydropower industry insisted on the importance of maintaining water levels in reservoirs between the lower and upper thresholds to avoid stressed situations.

In general, all interviewees seemed to be particularly interested on extreme weather information for the optimisation of the overall operations and adoption of prevention measures in case of extreme events. This special interest on extreme weather information has been also identified through the interviews of WP5 and is being considered in the development of S2S4E's decision support tool (DST).

f. Current deficiencies and needs of improvement

Throughout the interviews, experts expressed their unmet needs and complains about the available tools and weather information that is currently being used in decision-making processes.

<u>Reliability</u>

The greatest concern of interviewees is regarding the accuracy and reliability of S2S data. Most of the time the skill of S2S predictions is not specified, so experts make use of S2S forecast qualitatively to confirm quantitative prediction trends. Experts are currently trying to understand whether by improving the quality of the forecasts they can generate enough savings to justify an investment in improved models. However, the economic impact of those improvements is very difficult to simulate. In general, there is a need for reliable and high quality S2S information. Interviewees would like to know the skill of the forecasts to know the importance that should be given to the predictions.

Compatibility and coherence between models

One of the interviewees highlighted the importance of **the compatibility between operational models to allow a quantitative use**, particularly regarding the time resolution. For instance, seasonal forecasts (currently used on a qualitative way) have a monthly or three-monthly time resolution while operational tools run with an hourly or three-hourly time resolution. This difference is a barrier to the use of S2S data within the existing chain of operation models. Although other stakeholders did not specifically mention this issue, the cross-analysis of interviews highlighted an important interaction between operational models (production, demand, price, etc.).

Another interviewee complained about **the lack of an overall coherence** between all forecasts use to make the final decision. It was specified that each sector (i.e. wind power, solar power, hydropower, demand, etc.) use independent models to perform their predictions. Furthermore, different weather and climate datasets are often used as inputs. This strong independence was seen as an important deficiency.

Time horizon

Interviewed stakeholders do not necessarily share the same needs when it comes to time horizons. The DSO representative expressed his/her interest in receiving forecasts to cover the gap between short-term forecasts (next12 days) and seasonal forecasts (next 3 months). The interviewee would be interested on climate trends for the coming month, with a weekly scale, for example. Oppositely, another stakeholder working for an energy provider company recognised the need for longer-term forecasts such as three months ahead for hedging operations or seven months ahead for budget refinement.

Other needs

Finally, three other needs were exposed in the interviews:

- A trader stated that s/he would use seasonal forecasts that showed a trend with a probability above 80% to adjust financial decisions.
- For the hydropower production, it would be useful to improve knowledge on the initial states of snow (e.g., snow depth) at the snow melting period. This parameter is key for hydrological forecasts and of particular interest when snow melting has a significant impact on the calculation of water volumes.
- The use of S2S data differ a lot across companies. Big companies have internal expertise and modelling capacity, where S2S may potentially be used. However, the needs vary greatly from company to company, depending on the models they use and their product composites, and will have to be specified accordingly. Provision of S2S forecasts will therefore have to contain both raw data and processed data, which is not

provided today. Smaller companies may make use of more standardized sets of processed data to evaluate the uncertainties, but the reliability of the present forecasts are not good enough for this purpose.

2.2.2.2 Risk and uncertainty management

Once understood the typical decision-making processes, it is possible to dig into the management of risk and uncertainty to better understand how the S2S information would be taken into account by the companies and when they can really add value. Here, the attention is still on the decision-making process, but with special focus on finding what information apply to deal with risks and uncertainty. The questions (from 18 to 21 in Appendix I – Interview guide) were designed with background in decision-making theories, and modern investment theories in particular, with the purpose of exploring the possibility of establishing closer links between the production of S2S datasets and the decisions taken by the respondents. In the text that follows, the analysis of the answers is divided in a first description of the general findings and 3 core topics in line with the 4 questions posed:

a. Main lessons on the applicability of S2S for evaluations of uncertainty
b. Consequences of decisions that fail (from a forecast);
c. Benefits of correct decisions (from a forecast);
d. Practices on updating.

The answers are summarized below to reflect the needs of the entire company, but pointing out also answers given by the respondents reflecting different roles in a company, regarding consequences of failed decisions, benefits of correct predictions, and practices on updating.

*a. **Main lessons on the applicability of S2S for evaluations of uncertainty***

The ultimate concern of most of the companies interviewed is the financial outcome of their decisions, but there are no formal links between use of S2S data and evaluation of the uncertainties related to financial results. S2S data may be useful, e.g., for operating companies in controlling costs of maintenance and hydropower magazines. Regulatory public units have similar needs, depending on the role of the unit. The general problem is that they need an evaluation of the likelihood that the weather/climate will be as forecasted, which currently cannot be read from S2S model outputs. Nor do they have any formal procedures that might help them use S2S data to help them assess these probabilities.

b. Consequences of decisions that fail (from a forecast)

The main consequence of concern for the companies are the financial results, and thereby potential monetary losses. Within the companies, the consequences differ depending on the role of the department where the interviewees work. The concerns of traders are primarily on their expectations on market prices, which is closely related to the main concerns of the companies. Those working in departments with operational responsibilities, which includes maintenance and reservoir filling, report in most cases to other internal units. They must decide what to report to these units to provide them with reliable information about the risks and uncertainties related to the responsibilities of their own department. The risks to the companies thereby depend on the reliability of these reports. Less reliability implies less trust in the role that the department plays. Public units have regulatory responsibilities, for instance for allocation of inflow to water reservoirs in different power stations. Misallocation leads to a loss of the total benefits of the water reservoirs or areas and may be a source of conflict across companies.

Failures may propagate to later periods in some cases, such as postponing maintenance. Unexpected changes in inflow and tapping of hydropower magazines will change production possibilities in coming periods. In extreme cases, it may take years to get back to a "normal" situation after periods with minimum water capacity.

c. Benefits of correct decisions (from a forecast)

The benefits of basing decisions on correct projections is that the surplus of companies becomes as high as possible. Public institutions have different tasks, and their benefit is that the specific tasks are fulfilled in the best way. For the operation of the companies, it was pointed out, however, that being correct contributed to internal trust, which strengthened the role of the department in planning and budgeting, including their use of modelling and weather/climate data. It was also noted that the losses in being wrong may be more serious than the benefits of being right.

d. Practices on updating

It was pointed out by some modellers from energy companies that the use of S2S forecasts are hampered by the fact that it is impossible to get both raw data and processed data. S2S forecasts constitute only a part of the data needed for the modelling they do, and the companies need to transform the datasets to relevant time series, which requires both raw data and processed data. Respondents have tried to use what is available, but without success, because S2S data do not provide relevant information about probabilities. To illustrate the decision-making process, the example of a poker game was mentioned, where the gamblers reconsider the chance of winning each time they draw a new card. The new card turns the uncertainty of replacing a card in hand with an unknown card into a set of cards that cannot be changed. This makes it easier for gamblers to evaluate the chance of winning. Similarly, systematic updates of weather and climate forecasts with observations may improve the decision-making processes among the users of S2S services.

2.2.3 Provision of S2S information and development of a decision support tool (TOPIC 3)

The objective of the third part of the interview was to explore how the information can be adapted to be relevant to user-specific decision-making systems and current decision-making tools. Having in mind the Decision Support Tool (DST), interviewees replied to the set of questions from number 22 to 25 of the "Interview guide for user needs in S2S4E" (available in Appendix I – Interview guide). Subsequently, analysing the answers of all the interviews it was possible to highlight clear patterns. For simplicity, the relevant inputs collected were re-organized in the text below following the points listed hereafter:

a. The way of presenting the information (and ease of use);
b. Key elements, meaning the most relevant information the DST should provide;
c. Trustworthiness of information/data;
d. Experts' support.

*a. **The way of presenting the information***

Firstly, respondents were asked about the preferred ways for information/data to be conveyed.

There is common agreement among interviewees that the DST should provide raw data. In fact, this was one of the findings of the review of existing knowledge previously performed in chapter 1. From user needs gathered in past projects already emerged that users need and want to have ready to download the dataset provided. Some respondents would mainly exploit raw data analysing them in-house. Others are willing to use both raw and processed data. A respondent specified that, in its case, the optimal way of providing information would depend on the spatial scale at which they need the data. For instance, at local scale regularly updated data would be necessary to include climate data in their own energy models while at national scale a qualitative use of the information - as a map of scenarios - would be sufficient.

Interviewees are not concerned about the format in which data are delivered. This means that either NetCDF, .csv or other tabulated data formats seem equally adequate.

Generally, interviewees are familiar with the presentation of the information by means of heat-maps, online reports or seasonal outlooks. In conclusion, data visualization combined with downloadable datasets seems to be the preferred option.

b. ***Key elements***

For the DST to deliver maximum utility, interviewees identified priority features in line with their decision-making processes. Figure 7 shows the most relevant features expected from the provision of Sub-seasonal to seasonal (S2S) information. The results reported show the percentages of interviews in which each feature was mentioned as a priority. In the interviews where a feature was not raised it does not imply that the characteristic is not relevant for those respondents. It only suggests that they are more concerned about other characteristics.

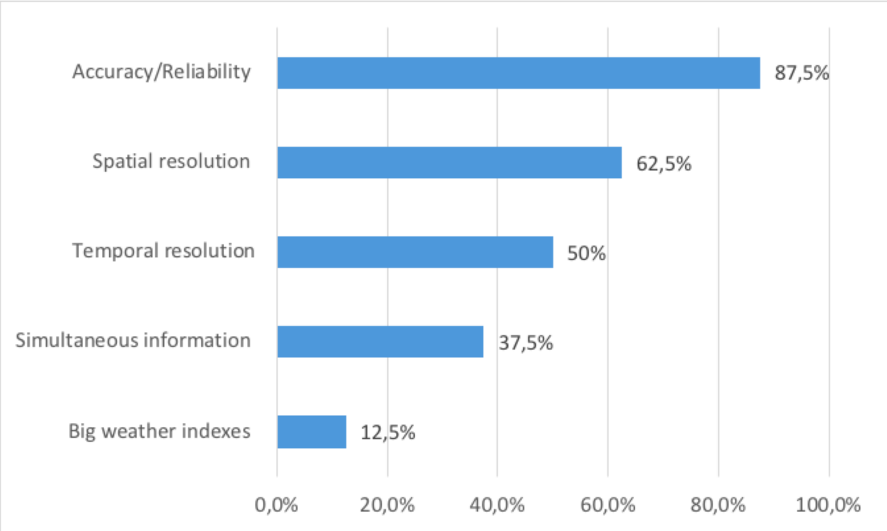

Figure 7: Key elements of DST according to respondents

Percentage of interviews in which respondents pointed *out each feature as relevant. Interviewees taking part in the same interview (and organization) unanimously agreed. Source: Interviews' answers.*

According to interviewees, accuracy and reliability of the forecasts is the most expected feature that the DST should guarantee. In fact, in 7 out of 8 interviews the issue was raised. High quality of the forecasts is a necessary condition for the uptake of the service. In terms of reliability, respondents were mostly asking for skill scores and, when not familiar with the technical terminology (as it was the case for respondents from the TSO), they asked generally for the failure rate of the forecasts. Hydrologists (R17 and R18) explained that long-term decision-making for hydropower currently depends on climatology hence it is important to provide them with the assessment of forecasts' performance having historical period as benchmark. R11 explained that s/he values more the reliability of the macro trends than an information with more spatial resolution but less reliable. Only in one company (R7, R8, R9 and R10) respondents did not seem to be particularly interested in skills, they would rather have more information from different providers to be able to make comparisons and finally "judge by themselves". The importance of reliability already emerged in the decision-making processes analysis (Section 2.2.2) as binding concern for the uptake of currently available information. Generally, forecasts' probabilities should definitely be available and some respondents set thresholds accordingly to decide whether to include an information in the decision-making process or not.

The second most common feature raised was the spatial resolution (reported in 5 of the interviews). To integrate forecast in the operational models currently in use the same geographical resolution is required. Different spatial resolutions needed in different organizations and within the same organization depending on the decision they are taking (for example, the interviewee from the DSO would expect consumption and production indicators given at local scale of each of the secondary substations (more than 2000) to calculate the electricity needs in the network. For R17 and R18 instead regional spatial aspects are important when the soil conditions of the basin are saturated, because this affects the inflow generation). This is also the case for temporal resolution, differently requested according to the usage envisaged. It is clearly of interest for interviewees, being mentioned half of the times as important element for the tool and previously (section 2.2.2) highlighted as main cause of incompatibility between currently used operational models.

The possibility of accessing simultaneously information about wind, solar, hydro is a particularly valuable characteristic for the respondents (3 out of 8), and R11 mentioned demand as well. Finally, information about big weather indexes - such as North Atlantic oscillation (NAO), Artic oscillation (AO)and Madden-Julian oscillation (MJO) – were highlighted as relevant information that they would like to have easily available in the tool (1 out of 8).

c. ***Trustworthiness***

The information should be rendered trustworthy to be taken up in the users' decision-making processes. According to the respondents, three main elements contribute in equal measure to build trust: 1) Accuracy and reliability of the forecasts 2) ensure users' understanding and 3) reputation of the provider. These elements were recurrent in the discussions being explicitly or implicitly addressed referring to information trustworthiness. For each of the three elements, some interviews dug into it showing particular concern. Overall, the measures to build trust indicated by the respondent are represented in Figure 8**.**

Clearly, accuracy and reliability of the forecasts are pillar for respondents' trust in the tool. However, effective communication is equally important. Interviewees appear more likely to rely on the information if it is conveyed in a simple, clear and comprehensive way. Similarly, the accuracy of a forecast can be appreciated if adequately understood. For instance, scoreboards can make information more readable and understandable by energy users who do not necessarily have knowledge of meteorology and/or climatology (as suggested by R1). The best way to ensure it is the correct understanding is the co-creation of these maps/indicators together with the end users. Finally yet importantly, provider's reputation makes information trustworthy (respondents from company 5 and 8). This also suggests the importance of transparency of the sources for every user to know where the information comes from.

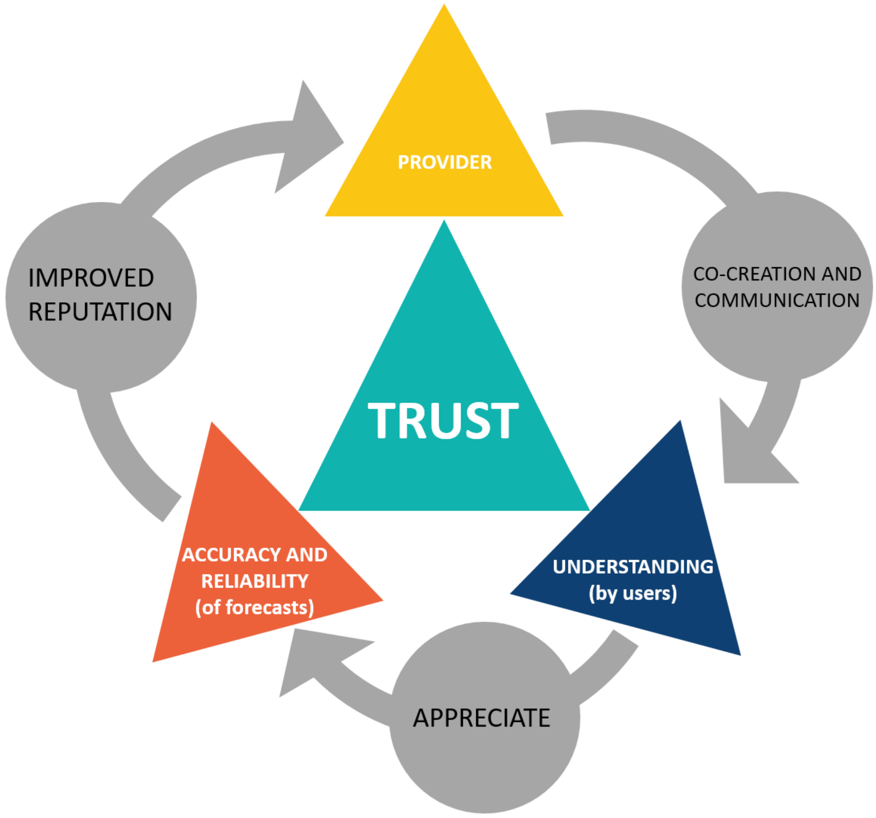

Figure 8: Building trust.

d. ***Experts support***

The project envisages the possibility of providing expert support as a service to the users with the goal of facilitating the understanding and inclusion in the decision-making processes of the information provided. *Webinars* are a common and highly appreciated solution. When asked about it, monthly frequency was recommended. During webinars, experts should mainly brief the users about newly released S2S forecasts (probabilities, uncertainty etc.). Moreover, these experts should provide guidance for evaluation by comparison of previous outlooks with the current situation. Past outlooks could also be published on monthly basis. A more personalised option than webinars are phone calls following the forecasts' releases. These might facilitate the discussion of the results by one to one conversations. Generally, for respondents' purposes the in depth understanding of the methodologies applied is not necessary, however some of them may be interested to have the possibility to do so. For instance, R15 and R16 would appreciate to know about scientific evidence for skills.

Only one respondent (R11) claimed not to be interested in expert support. The idea is that no support will be needed if the tool provides self-standing conclusion. However, the vast majority showed interest in the additional support.

2.2.4 Final remarks

The in-depth interviews allowed to better understand the needs and expectations of potential users thanks to the detailed information gathered from 18 respondents representing 8 different companies and characterised by different profiles (from meteorologists to traders). In this way, the sample covered the most relevant of decision-making processes that depend on weather and climate conditions. Results highlighted that the perspective changes according to the interviewee. Each respondent faces various types of decisions and has different expertise, both influencing their priorities and expectations from a climate service (e.g., in terms of weather and climate variables temporal/spatial resolution or way of delivery of the information). The interaction with the interviewees allowed identifying some common patterns as well as discrepancies. This information confirms some previous trends but also derives relevant lessons.

As spotted during the review of existing knowledge (chapter 1), in-depth interviews' results confirmed that users are exploiting weather and climate information but normally they still do not make a quantitative use of S2S forecasts. Respondents continue to point out the lack of accuracy and reliability of the forecasts as the main barrier for the uptake of S2S forecasts. Moreover, the interviews conducted confirmed that downloadable datasets of the forecasts are needed because many respondents perform in-house analysis. It has to be noticed that the interviewees were prevalently advanced users with two thirds of them having post-processing capacity in house.

The in-depth interviews investigated further users' needs and brought up new findings as well. Even if there is no quantitative use of S2S forecasts yet, there is increasing interest and respondents declared that they are approaching S2S information by starting to make a qualitative use. To ease the uptake of S2S forecasts, the analysis of the conversations with respondents tried to explain their expectations from the DST. Among other findings, we identified some recurrent elements that contribute to build trust in S2S information. Three main elements interconnected to each other contribute to the trustworthiness of the forecasts: i) the accuracy and reliability, ii) users' understanding of the information – which depends on the way it is conveyed, and iii) the reputation of the provider.

With respect to the integration of S2S forecasts on decision-making processes the major enablers are financial gains or avoided losses. However, these enablers are counteracted by forecasts failure that is a major barrier. According to respondents and assuming that they started to take decisions based on S2S information the failure of a forecast would cause higher damages than the benefits of a successful one.

Finally yet importantly, decision-making processes explained during the interviews were further analysed to allow for a clear understanding of the key decisions and how weather and climate information support them. For this purpose, decision-making maps were created (section 2.3). The analysis highlighted strong dependency on weather and climate conditions for all the decision processes even if decisions do not have all the same goal (e.g., guarantee supply to costumers or safety of workers). However, in the majority of cases there is an economic aim

2.2.4.1 Opportunities

Drawing from the current deficiencies of weather and climate forecasts and from the challenges that (potential) users, S2S4E is working on the Decision Support Tool (DST) to bridge these gaps.

First of all, the DST will provide the skill of the forecasts to improve reliability, which is considered the biggest issue according to our knowledge. The assessment of forecasts' performance will have the historical period as benchmark to facilitate the switch from climatology (currently used) to S2S forecasts (that will be provided by the DST).

Another opportunity of the DST is its objective of providing seamless predictions of different time scales (sub-seasonal and seasonal) and incorporating in the same tool forecasts for wind energy, solar energy, hydropower and demand. By doing this, the DST will facilitate the access, comparison and interpretation of the climate forecasts for the users making transparent to the user the differences in the prediction systems for each time scale.

In general, the DST will be shaped to accommodate user needs as far as possible taking advantage of all the knowledge gathered. Key elements have been identified and prioritized as a result of the interviews. However, acknowledging that there are user-specific needs, more personalized solutions, mentoring or expert advice can be envisaged as a complementary part of the climate service provided by the DST (e.g., in terms of spatial resolution, climate interpretation, forecast outlooks webinars).

2.3 Decision maps

2.3 Decision Maps of weather and climate dependent decisions

The In-depth interviews and the answers to TOPIC 2 questions (see section 2.2.2) provided not only a general overview but a more detailed vision of the decision-making processes affected by weather and climate conditions. Below we provide a description of specific weather and climate dependent decisions with a detailed explanation of the steps of the decision-making process (decision map) and the climate variables used for those decisions.

Energy trading and hedging

Category: financial decision
Type of stakeholder: energy producer & provider

Energy trading is remarkably supported by weather data as energy prices oscillate according to energy demand and supply changes. Therefore, weather and climate information to forecast energy production potential and electricity demand is of high interest for energy traders.

Trading decisions are often based on short-term data, whereas hedging decisions are supported by long-term data, as they refer to investment or transaction decisions to reduce the risk of adverse price movements of an asset in the long-term. Normally, in the energy sector, a hedge consists of a financial product that offsets the risk of loss, such as a futures contract. By hedging, energy traders avoid money losses and budget disruption in case of wrong estimations.

The same climate variables used for trading decision-making process are used for hedging, but on a different time scale. The main variable used to estimate the demand is temperature, which is often combined with the economic parameters of available energy demand models. On the other hand, to estimate the energy production potential, the climate variables used are solar radiation, wind speed and direction, precipitation and hydro-meteorological information.

The decision-making process for trading can be described in few steps:

1. Data analysis: Estimation of the energy supply and demand. Some interviewees reported the qualitative use of S2S data for this analysis. Traders from one of the energy companies interviewed, explained that they have a power price forecasting model, used to translate meteorological information into wind production levels, solar levels, hydro-production levels.

2. Market analysis: Understanding of prices, competitors, demand and supply.

3. Sale or purchase: Estimation of cost and benefits of possible actions. The decision of buying or selling will be based on a cost-benefit analysis.

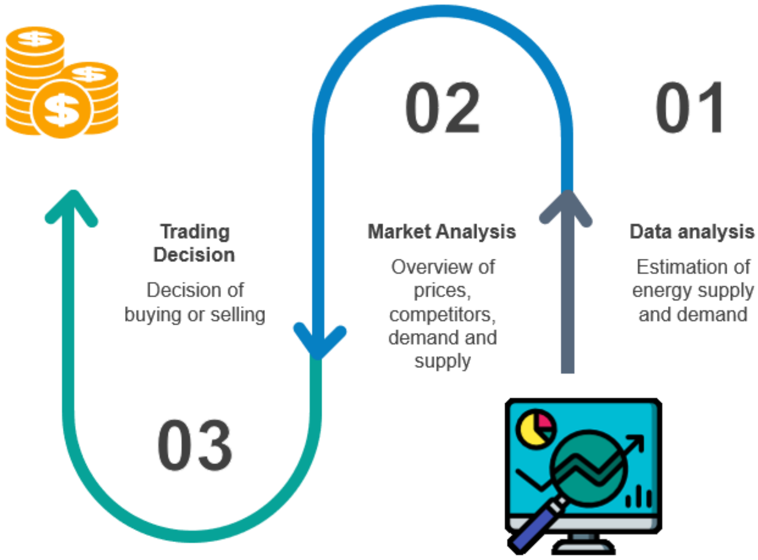

Figure 9: Energy trading decision-making process

When doing hedging, energy traders sell in advance the production that they are expecting to have in a given moment. For example, if the production is expected to be equal to 20MWh in July 2018 the company may go ahead and sell 18MWh committing to that production. If predictions fail and the company produce only 10MWh, something needs to be done regarding the other 8MWh sold but not produced. The cost associated with this deviation is the financial cost that the company bears in case the prediction fails. In order to avoid such financial risks, hedging follows trading's decision-making steps and introduces an additional final step to reduce financial risks of long-term transactions:

4. Adoption of financial mechanisms: Financial mechanisms such as futures are adopted to avoid economic losses related to long-term financial transactions.

Figure 10: Hedging decision-making process

Production planning

Category of decision: operational decision
Type of stakeholder: energy producer & provider

Energy producers often count on different means for energy production. According to expected energy production from renewable means and to the demand, the most cost-effective energy production source is chosen. Operational and strategic decisions are interlinked for energy producers. Weather forecasts are used to estimate energy production from renewable means of production, to estimate consumption and prices.
The weather parameters used to estimate the energy production potential of renewables are: Solar radiation, wind speed and direction, precipitation and hydro-meteorological information. Moreover, production decisions are also based on demand estimates that rely mainly on temperature forecasts used for the development of scenarios.

The production planning decision-making process can be described in the following steps:

1. Forecast of demand/consumption: Consumption scenarios are created based on weather data. The optimisation of an energy producer interviewed develops 121 annual consumption scenarios based on weather conditions (time scale: half-hour, update frequency: quarterly). Then, the number of scenarios is multiplied by 4 (484 scenarios in total) taking into account economic variables.

2. Estimation of market prices of electricity: Based on temperature market prices of electricity are estimated. The price of each day is in a way dependent on hydrology, on fuel prices, gas and coal prices, etc.

3. Renewables production estimation: Wind and solar energy productions are forecasted.

4. Realization of the "merit order": Considering the available means of production, are defined the production costs for each mean (paying attention to the value of water). Then, the planning of the means of production is done on a merit order from less costly to the costliest.

5. Market security actions (decisions): It is decided to buy or sell electricity, to schedule a shift in the means of energy production and to use or storage water (hydropower production).

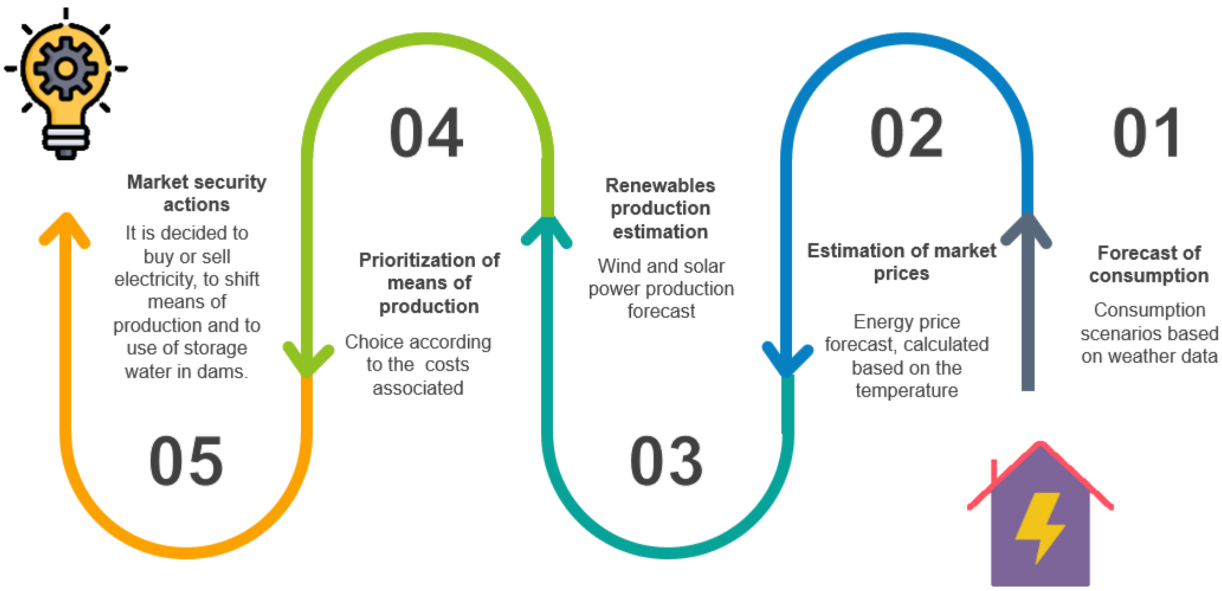

Figure 11: Operational decision-making process

At the optimisation department of one of the energy companies interviewed, the macro production planning is done on an annual scale, this exercise is performed and reviewed every 15 days. On the other hand, according to some hydrologists interviewed, production planning is built according ice melting and seasonal changes. Their objective is to fill the reservoirs in the summer time with the spring floods and use the water in the winter time when the energy demand is high.

<u>Maintenance planning:</u>

Category of decisions: maintenance decision
Type of stakeholder: energy producer & provider

The decision of when to perform maintenance of energy production plants is based on the production planning, which is based on weather, consumption and prices estimates.

The same weather parameters used for production planning are used for maintenance scheduling, as maintenance is done according to production activities, when energy production plants are not active.

The maintenance decision-making process can be described in the following steps:

1. Forecast of consumption: Consumption scenarios are created based on weather data.
2. Estimation of market prices of electricity: Based on temperature market prices of electricity are estimated.
3. Realization of the production planning and choice of the most cost-effective energy production means.
4. Maintenance scheduling: According to the production planning maintenance is scheduled and performed.

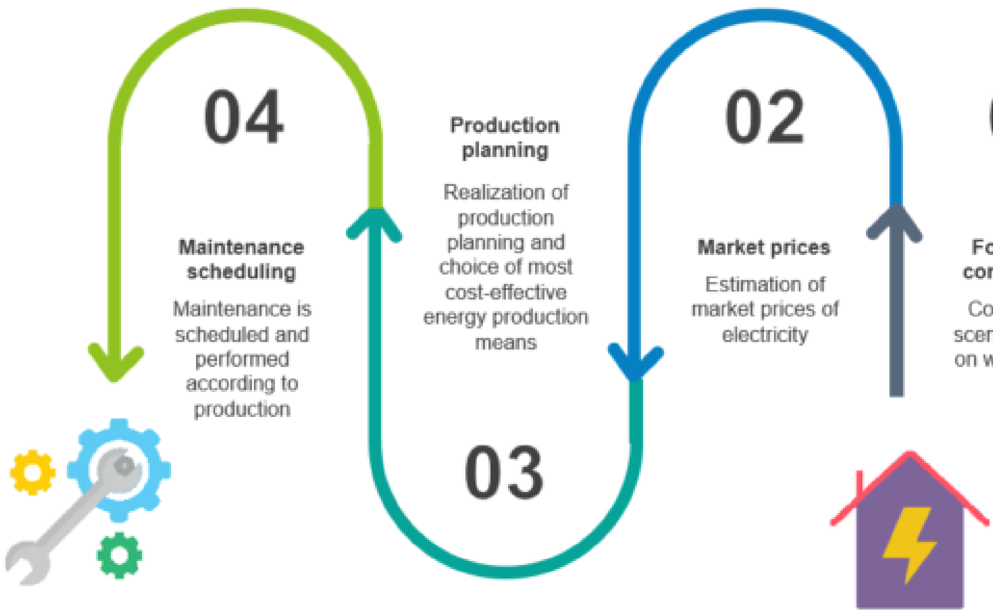

Figure 12: Maintenance decision-making process

All time scales (hourly, daily, 2-5 days, weekly, monthly, seasonally, annually) are part of the operational planning. Seasonal and annual are more for the long-term planning. Even the decadal scale is used to understand climate change and how this can affect production plants safety. Decisions made at different timescales are the same but subject to more or less stress and flexibility. For example, the delay of thermal and hydraulic power plants for maintenance is possible at a monthly time horizon, or even weekly in certain cases, but not in the shorter term.

Management of the electricity transmission bill

Category of decisions: contractual decision
Type of stakeholder: DSO

Energy distributers make use of weather information for the network management, concretely for the electricity transmission bill management, which is an ongoing process throughout the year.

Winter is the most decisive season for most of the secondary substations of the electricity network. For this reason, winter is considered as the entry point of the process. The management of the electricity transmission bills can be described in the following steps:

1. Study of subscriptions made in the past: For example, grid planners establish a range between the minimum and the maximum subscription values for each of the 2300 source positions based on the last 3 years.

2. Consideration of medium-term forecasts: Temperature trends for the coming season are used to place subscription within the expected range for the coming year. For instance, in a cold winter, they stand directly at the top of the range of subscription. On the other hand, in a mild winter, they place themselves at the bottom of the range, allowing themselves the possibility of going back up during the winter.

3. Adjustments: Few adjustments are made on the electricity transmission bill based on short-term forecasts. The current subscriptions are studied and potentially modified on the basis of D+12 and D+4/5 forecasts. Subscriptions can theoretically be changed daily. In fact, they are changed in average once a month because the following rules shall be considered:

    a. Subscriptions are made for 1 year.

    b. Subscriptions cannot downgrade during its term (1 year).

    c. There is a firm notice period of 3 business days to change an existing subscription.

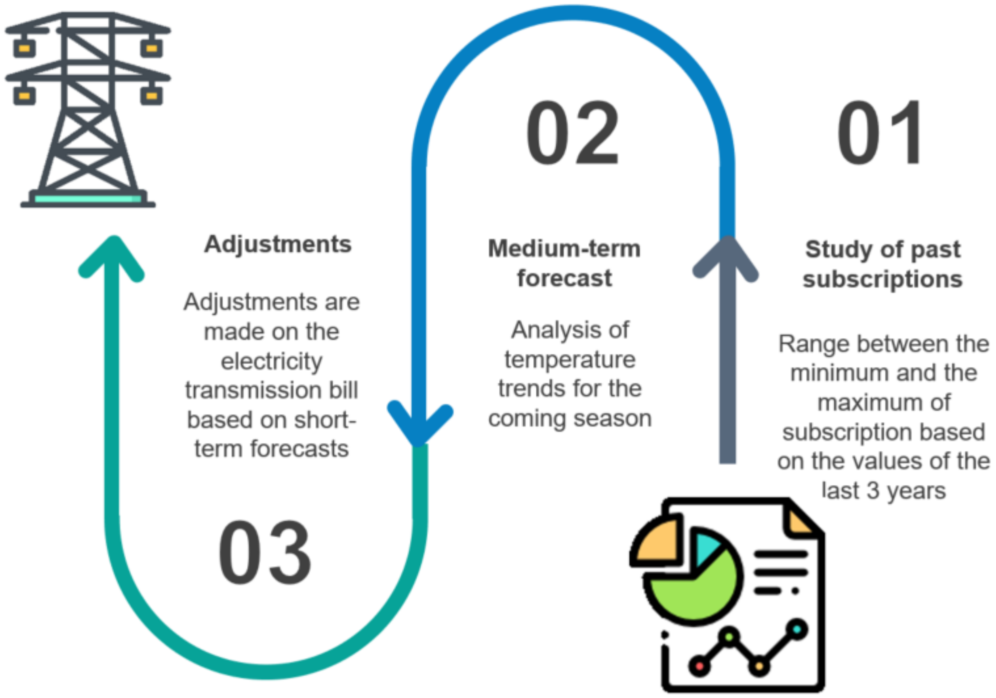

Figure 13: Contractual decision-making process

2.4 New Case studies

2.4 New Case studies

During in-depth interviews, respondents were invited to think about anomalies that where of particular interest for them because of the impacts on their activities. Four relevant examples were selected as case studies that exemplify the challenges that S2S4E aims to address. In their words, these case studies are the result of experiences they had to manage behind the lack of a skillful S2S DST tool. In the choice of the case studies priority is given to those of interest for partner companies of the project. However, some are also inspired to the needs of third parties that participated to interviews.

This section will be dedicated to explore these four new case studies suggested by interviewees. It is important to note that these are additional to the previous four case studies suggested by partner companies at the beginning of the project. The complete list of eight case studies (four previously detected and four new ones) is reported in Table 8.

Table 8: Full list of case studies

#	Period	Time horizon	Region	Implications
Case 1	17-23 Jan 2017	Sub-seasonal	France, Germany	Wind, hydro, demand
Case 2	23-29 Jul 2013	Sub-seasonal	Germany	Demand, solar, hydro, wind
Case 3	30 Aug–5 Sept 2016	Sub-seasonal	Spain	Wind, demand
Case 4	May–Jul 2015	Seasonal	Sweden	Hydro
Case 5	28 Jan-3 Feb 2014	Sub-seasonal	Romania	Cold spell, impact wind power
Case 6	Jan-Mar 2015	Seasonal	USA	Wind
Case 7	27 Feb-5 Mar 2018	Sub-seasonal	Europe/ France	Demand
Case 8	Mar 2018	Seasonal	Spain	Wind, solar, hydro, demand

The new case studies that emerged during in-depth interviews are presented in this chapter. According to the table above, these are the cases from number 5 to 8. The remaining ones are available in Appendix III – Already defined case studies. Cases were selected in such a way to ensure balance between examples of seasonal and sub-seasonal, variety of variables impacted (e.g., hydro, solar, wind and demand) and a comprehensive geographical coverage.

The case studies introduce the anomalies (period, region, weather and climate variables involved etc.) and the impact on the company affected. They will serve to understand how potential users would have benefited from S2S forecasts in these contexts and help defining the DST accordingly.

Finally, it is important to say that the deliverable D4.1 "Benchmarking skill assessment of current sub-seasonal and seasonal forecast systems for the users' selected case studies" will be fully dedicated to analyze these 8 case studies in a deeper and more technical way.

The figures are made using ERA-Interim reanalysis (Dee et al., 2011).

2.4.1 Case study 5: Severe weather conditions in Romania – winter 2014

Period / Year	28 Jan – 3 Feb, 2014
Time horizon	Sub-seasonal
Region	Romania
Implications	Wind Power (Icing & O&M)

On 31 of January, 2014, the European Commission's Directorate-General for European Civil Protection and Humanitarian Aid Operations, reported that severe weather conditions (heavy snowfalls, low temperatures and rainfall) in central and eastern Europe, particularly Romania, caused power outages, and transportation problems. In Prahova (center-east of Romania), 8,500 families suffered from power failures (Reliefweb, 2014).

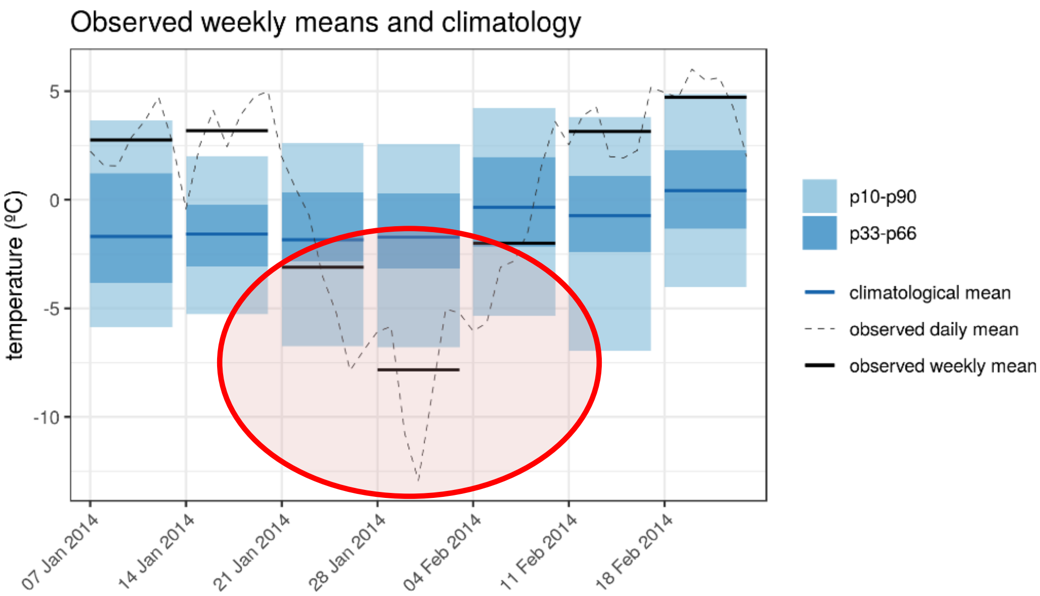

Figure 14: Observed weekly means and climatology, temperature, Romania, from January 21 to February 4th 2014

Figure 14 above shows that the temperature weekly mean observed for the period from January 21 to February 3th, 2014, was below the climatological 10th percentile in the region of Romania.

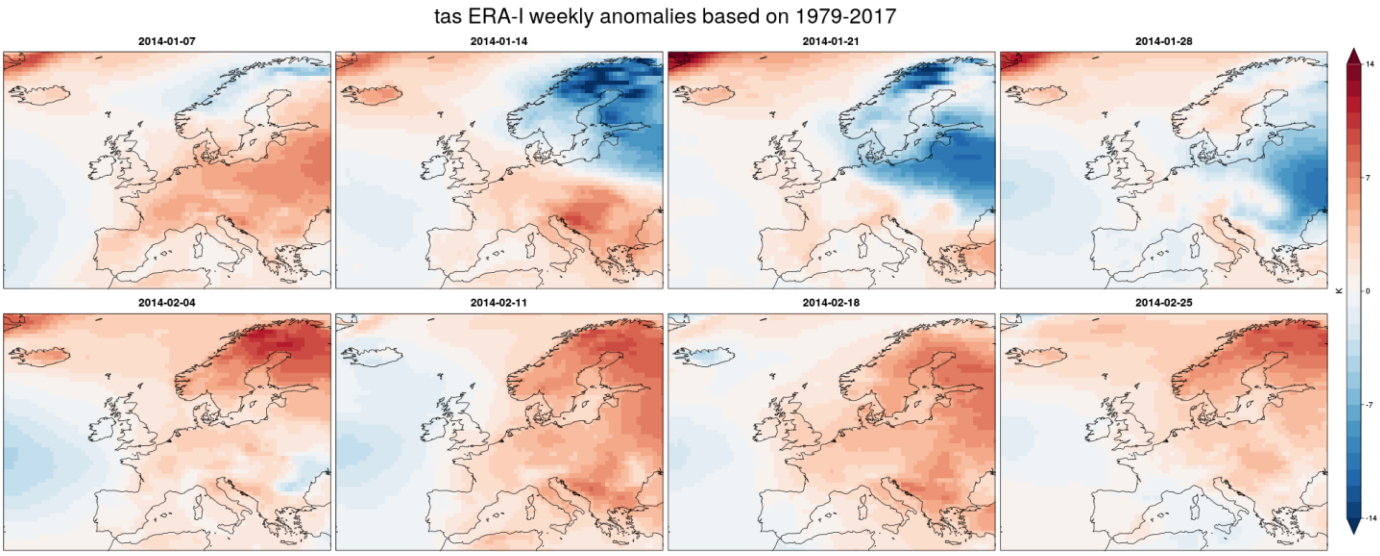

Figure 15: Weekly anomalies, temperature, from January 7th to February 25th 2014

In Figure 15 we can observe the temperature anomaly in the region of Romania in the week of January 28th, 2014. A respondent reported that it was a very intense icing event in January and February 2014 in Romania. In some of their wind farms, both the rotor and the accesses to the farms were frozen for several days. The parks, mostly in the center and south of the country, were stopped and, in some cases, they were without any signal reception. When the park manager could not access, the day ahead market offers had to be corrected manually. In Table 9 are the icing starting-ending dates of affected wind facilities of the company involved

Table 9: Icing dates of affected wind facilities

Wind Farm	Icing: start-end dates	
1	25-Jan	28- Jan
2	19- Jan	07-Feb
3	19- Jan	07-Feb
4	25- Jan	28- Jan

The impact of this event, in addition to the losses inherent to the sale of energy, came from the cost of deviations of the manual correction, based on what had happened the previous day. The worst situations were the installations' transients between start and stop. In Romania, the legislation is quite restrictive in this sense, and these deviation costs per MWh are usually very high. The respondent indicated that knowing one or two weeks of anticipation would be useful, at least to prevent the control center and take action.

Finally, the anomaly had also media impact, since different news reported that this was the first time that Romania's National Administration of Meteorology issued the red code warning in six areas of the country (Euronews, 2014 and AFP, 2014).

2.4.2 Case study 6: USA wind drought – winter 2015

Period / Year	Jan - March, 2015
Time horizon	Seasonal
Region	USA
Implications	Wind power

During the first months of 2015 (January–March), surface wind speeds were well below normal in most of the contiguous United States, which reduced substantially the power generation of most of the wind farms in the west region of the country.

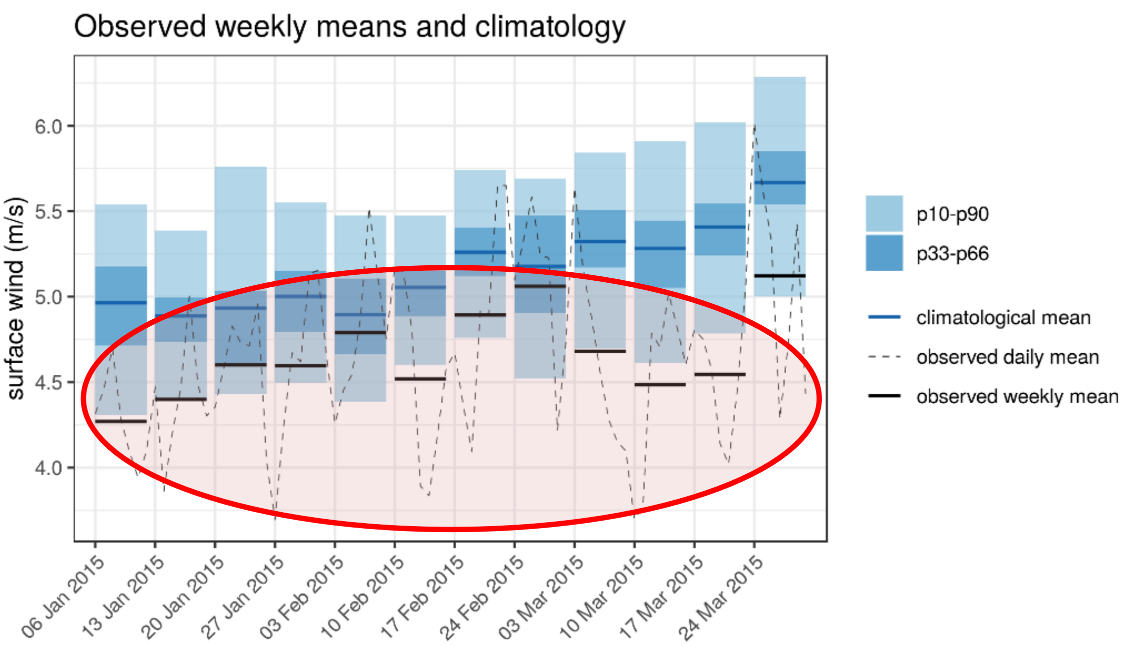

Figure 16: Observed weekly means and climatology, surface wind, USA, January to March 2015

Figure 16 represents west region of USA observed surface wind speed weekly means from January to March 2015, rated below normal historical climatological mean.

In the American West, average wind speed were 20% below normal in the first 2 quarters of 2015, causing wind farms electricity output to fell 6%, according to the Energy Information Administration. The wind speed reduction was especially relevant in Texas, Oklahoma, and Kansas, where most of the biggest wind farms are concentrated (Figure 17 below).

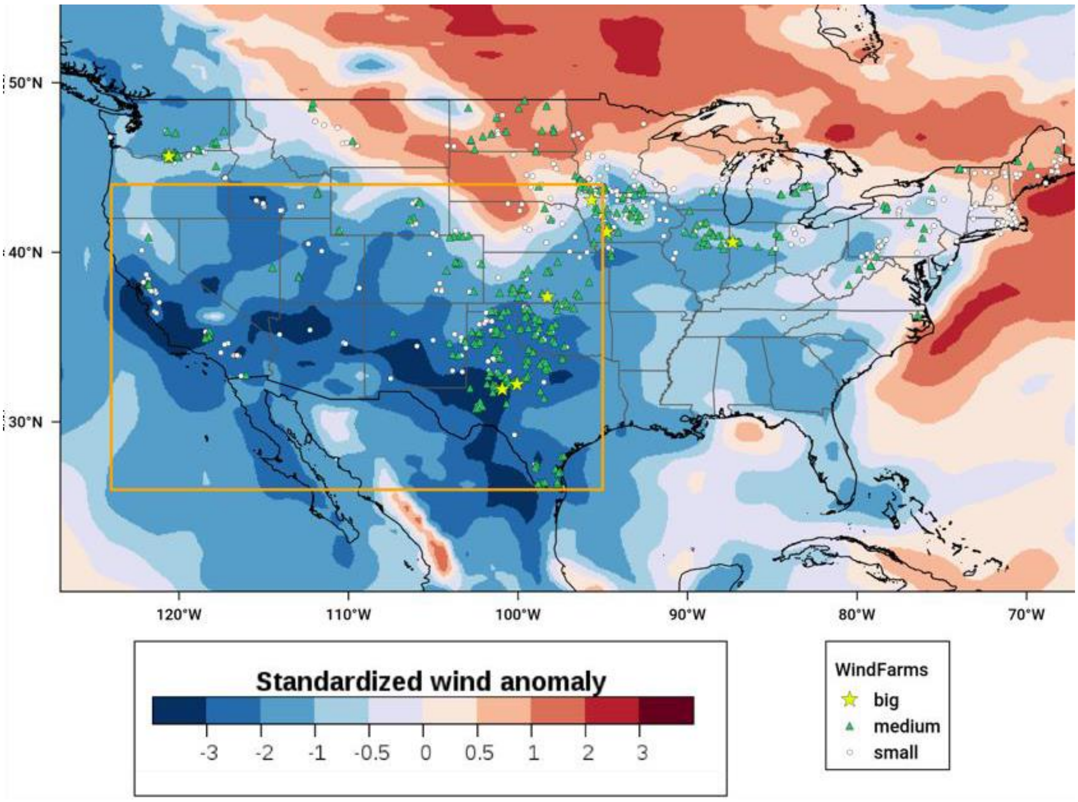

Figure 17: Wind speed anomalies reflecting the wind drought over the United States for the first trimester of 2015. The US wind farm fleet is also shown.

Source: Lledó et al. 2018.

Indeed, the wind industry did not anticipate such low wind episode. Some companies experienced financial problems due to the lack of energy production and revenues and there were concerns on the value of the assets. Therefore, some questions arose in the minds of many in the wind industry: When would winds revert to normal conditions? Did anthropogenic climate change have an influence on this episode? Could this episode repeat in the near future?

Finally, some newsletters, like Newscientist, continued publishing about this “mysterious” anomaly, since it seemed to repeat the pattern in the beginning of 2016 (NewScinece, 2016). Moreover, because it seems that if this pattern remains, it could cause investors to have second thoughts. As they quote in their February 22, 2016 note: “investors naturally want to understand what happened in 2015, and what to expect in the future”.

2.4.3 Case study 7: Cold spell in Europe – 2018 winter season

Period / Year	27 Feb – 5 Mar, 2018
Time horizon	Sub-seasonal
Region	Europe / France
Implications	Power Demand

At the end of February 2018, a sudden stratospheric warming occurred over the northern polar region and led to several weeks of extreme cold temperatures over most of Europe, as well as persistent dry conditions over the Scandinavian Peninsula. Due to the cold temperatures, energy consumption increased in the areas affected.

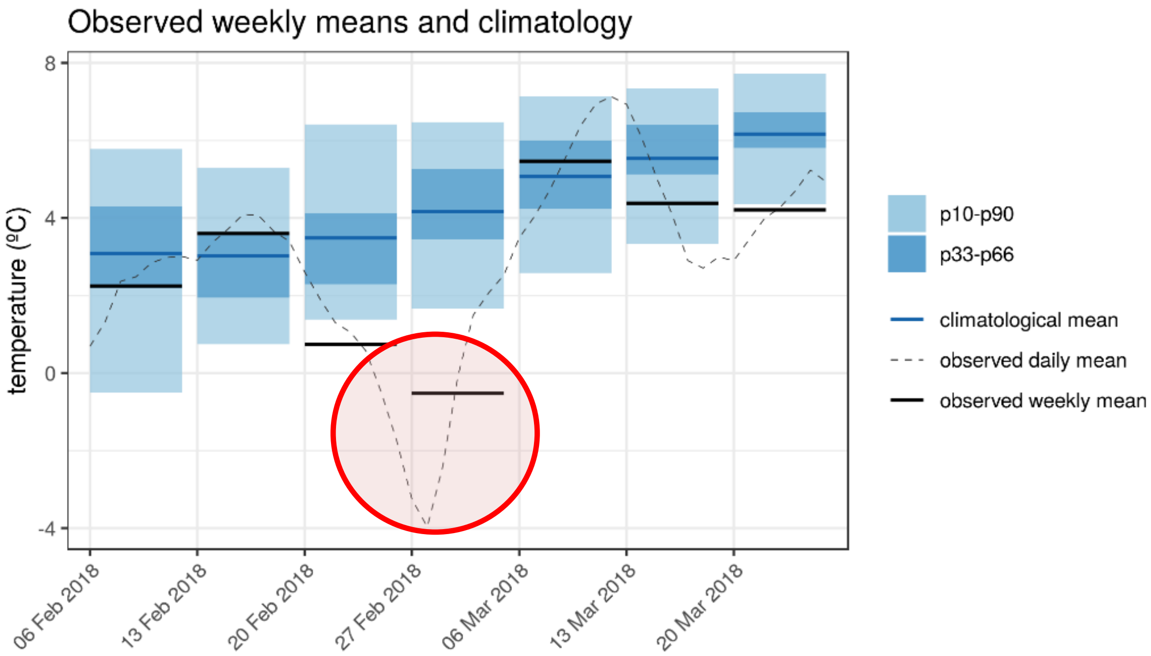

Figure 18: Observed weekly means and climatology, temperature, Europe, 27th of February to 5th of March 2018.

Europe’s temperature observed weekly mean were rated below climatological mean, for the last week of February and first week of March, 2018.

A respondent remembered the most recent cold spell in Europe, in the winter season 2017-2018, and the repercussions they had because of the lack of a good skill in the prediction of SSWs.

The seasonal reports by Météo France announced a rather mild winter. This information led the respondent to consider the possible cold spells as temporary anomalies and thus they did not systematically increase the energy transmission subscriptions.

1st cold wave - end of November, beginning of December: Météo France announced the cold wave more than 5 days before. However, the respondent decides not to react (or very little) because they believed the episode was a temporary anomaly in a mild winter context.

2nd cold wave - mid-December (around the 15/20 December): This time, Météo France did not forecast the wave until the day before or two days before. For the respondent it is already too late to react. Strong overtime penalties had to be paid.

3rd col wave, from February 27 to March 03: The third wave was the most important cold anomaly of the winter. Météo France forecasted it but the respondent decided again not to modify the subscriptions. Their rationale was simple, since winter is the most dimensioning season, they thought it was better to avoid increasing the contractual power at the end of winter.

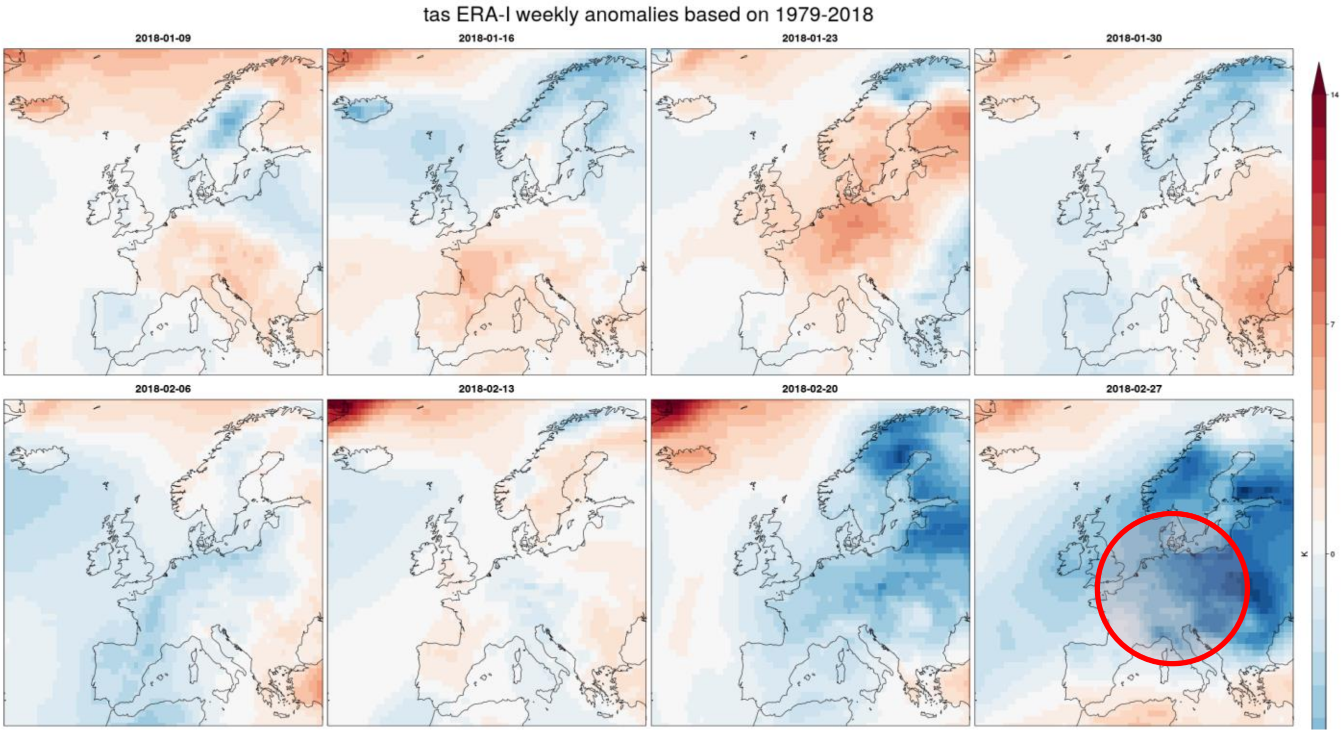

Figure 19: Europe weekly temperature anomalies from January 9th to February 27th 2018

In Figure 19 we can see the most important wave in the last week of February that year.

In the media, this phenomena was named "The Beast from the East" by the British press, and had very high coverage behind the consequences it brought mainly for public health, security and energy prices (Business Insider, Euronews, 5 News, BBC News, The Thelegraph, and Reuters, 2018).

2.4.4 Case study 8: High wind and cold spell in Spain – March 2018

Period / Year	Mar, 2018
Time horizon	Seasonal
Region	Spain
Implications	Wind, solar, hydro and demand

In March 2018, the winds were much higher than normal in Spain. This anomaly was accompanied by significant precipitation, and slightly lower temperatures than normal throughout Europe, which increased the power demand. In Spain the observed surface wind speed was well above than the climatic 90th percentile for four weeks in a row.

This anomaly had several implications. In one hand, the wind production reached 6.937 GWh, 62.7% higher than the same period last year, and accounted for 33.1% of total country power generation of that month. On the other hand, the return of the rains allowed hydraulics to have an important contribution of 19% of power generation.

Energy prices also reflected this over power generation, since they were lower than usual (40€/MWh). Nevertheless, these prices did not reach the lowest historical prices, maybe behind the increased demand for heating because the low temperatures.

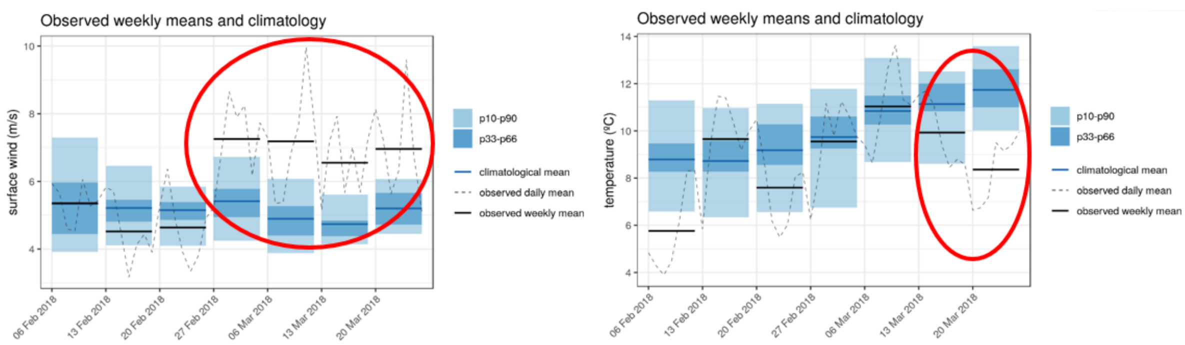

Figure 20: Observed weekly means and climatology, surface wind and temperature, Spain, March 2018

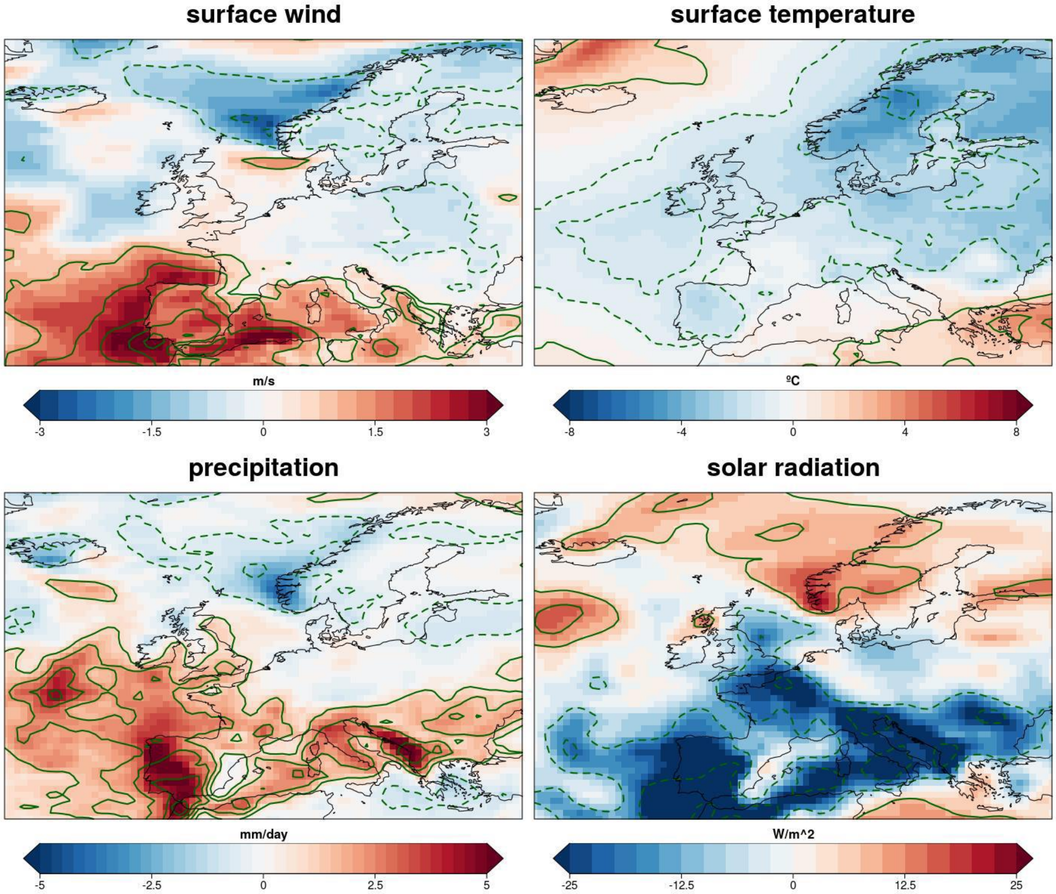

Figure 21: High wind, precipitations and low temperatures observed anomalies, Spain, March 2018.

Concluding discussion
Bibliography
Appendices

3 Concluding discussion

This report offers a guide through energy users' needs in terms of weather and climate information with focus on S2S forecasts. Starting from an overview of the knowledge gathered from previous projects, S2S4E designed and performed in-depth interviews with a selected sample of users. Subsequently, the report presents the analysis of the results and finally it offers four practical case studies to show how S2S forecasts can impact the decision-making processes of energy companies.

We acknowledge that the users engaged in the interviews were mostly advanced profile users. This is due to the high-profile industrial partners of the project and likely because advanced users are more prone to be engaged than other types of users. Advanced users working within large companies that have more resources to allocate to research/prospection of new methods are the ones that have been more active in participating in co-design. This sample bias clearly affects the results, shaping the DST for advanced users, although it will be characterized by a simple and clean design. However, creating a tool that is well functioning for advanced users is a proof of concept. It can demonstrate the potential utility and it will be the base to engage with other types of users. Active participation of different users will promote the development of the tool in a way that it will better fit their needs as well. To overcome this bias, other services around the DST have already been planned in the project (e.g., webinars, outlooks, tutorials etc.) that can be adapted to various types of users.

This study detected recurrent users' needs that persist, being already spotted in previous projects. Together with these needs, thanks to the interviews it was possible to get a deeper understanding of the decision-making processes, and hence finding out new ones. These findings constitute precious information for tailoring the DST so that S2S forecasts will add-value to energy companies. While clarifying how S2S forecasts can better support decisions of different kinds, the interviews served also to identify barriers to the uptake of the forecasts. In section 2.2.4 we describe some opportunities for the DST to overcome certain barriers. Anyways, considering our sample, there is a positive trend in the interest of energy users in S2S forecasts. Users are seeing more and more the potential added value of S2S forecast in their decision-making processes and the DST will offered a tailored support to facilitate the uptake.

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5 Appendices

5.1 Appendix I – Interview guide

Introduction/Background

- Professional backgrounds of the interviewee(s)
- Current position(s) in the company
- Role(s) and tasks of the interviewee(s) – including their role in the development, implementation and evaluation/assessment of the decision support tool (DST) to be developed

Expected output data: *Background information on how professional background, position and roles/tasks may affect the current use of S2S information, and how current use relates to what sorts of decisions, uncertainty- and risk management.*

Topic 1: Weather and climate information: current use

1. Which weather conditions (e.g., temperature, precipitation, wind, solar radiation, snow cover, wave height) matter (most) for decisions in your company's core operations?

1.1 Why and how?

2. Of each relevant weather condition, which *aspects* matter most for the decisions you make, and how?

2.1 Temporal aspects (e.g., duration, frequency, intensity)
2.2 Spatial aspects (geographical scales, e.g., regionally, locally)
2.3 (Particular) Combinations of such aspects

3. Which weather and climate information/datasets do you use?

3.1 Do you use weather/climate information data straight from models [raw data] or processed information – or both?
3.2 Why did you choose that data?
3.3 Are the data processed in-house or by an external information provider?
3.4 Are the data (and tools) you use provided for free, or do you pay for these services?

4. Do you record/register/analyze the historical impacts of weather and climate on your organization's operations?

4.1. In that case, how do you use that information?

5. Which weather and climate forecasting tools do you currently use?

5.1 Why these?

6. Specifically, please describe how (if at all) your company currently uses what S2S forecast information for what operations and decisions (e.g., running operations, maintenance, market decisions etc.). If you do not use S2S information, please explain why. Try to be as specific as possible.

7. Do you perceive any deficiencies in the information and tools you currently use? In that case, which ones, and why? Are there any gaps between what information you currently possess, and what information you ideally would like to have?

7.1 In that case, which gaps?

Expected output data: *Information about how the companies (in general terms) use what climate/weather/S2S information and tools for which operational functions.*

Topic 2: Decision-making and risk management

Decision-making processes in general

8. Which/what sorts of decisions in your company are sensitive to expectations about S2S weather conditions?

8.1. How and why?

9. Please describe the decision-making process of the most important decisions sensitive to S2S weather conditions.
   - Try to be as specific as possible, and use examples, drawings etc.
   - Also try to differentiate between operational and strategic decisions.

10. Specifically, which tools do you currently use when making specific decisions relating to S2S temporal scales weather conditions (e.g., economic/price models, hydrological/meteorological models, technical/operational models etc.)?

10.1. How do you use this information/these tools (quantitatively, qualitatively – or both)?
10.2. How do these tools interrelate?

11. Are there any climate- and/or weather-related critical thresholds (e.g., magazine levels, probability of a certain wind speed level) that are of particular interest for decisions in your organization?

11.1. In that case, which ones?
11.2. How are these thresholds linked to specific decisions?

12. Which particular S2S metrics, indices and/or indicators (e.g., capacity factor, inflow anomalies, consumption rate) do you consider most critical for your decisions?

12.1. Why these?

13. Generally, is there anything lacking with your current information and tools for being able to make better S2S-related decisions, as seen from your company's perspective?

13.1 In that case, what?

The case study/studies:

14. Think about the case study you provided in the project proposal, and try to think of an **additional case**. Which decisions relating to weather/climate information were made? Which weather/climate information did you use when making the decisions, and how? Did you use S2S information? Why/who not?

15. How often did you update the forecasts? If the forecast for a certain period differed from what you previously had expected, how did that affect your decisions?

16. Think of specific decisions related to the case. For each decision, what information would be considered to be the most useful: a range of possible outcomes for relevant climate indicators (minimum, maximum and expected value), or an estimate of the probability of certain events, or a combination of the two (probability with minimum, maximum and expected value)?

17. How (if at all) could S2S forecast information/indicators *ideally* have assisted you in making better decisions? What tools and information (broadly speaking) were you missing/lacking (in hindsight)? How should the information have been provided (when and in what format)?

Risk and uncertainty management

18. Which weather- and climate-related decisions need to be taken on what timescales (hourly, daily, 2-5 days, weekly, monthly, seasonally, annually, decadal scale(s))?

18.1. What is decided, and what is the overall purpose of the decision?
18.2. For how long are these decisions considered binding?

19. What are the consequences if you base a decision on expectations (from a forecast) that fail?

19.1. How sensitive are the consequences to the deviation from the expectations (from the forecast) on which the decision was based?
19.2. Do consequences of decisions based on failed expectations propagate to later periods, and if so, how and over how long time?

20. Which are the benefits of basing a decision on expectations (from a forecast) that turn out to be correct?
21. Imagine you are provided with forecasts for the next month and each week. As you get closer to the predicted month, you are provided with an updated forecast for the same month. To what extent/how/when are your expectations from the original forecast updated if new forecasts differ from the previous one?

Expected output data: *Information about how the companies use what climate/weather/S2S information for which decisions, both generally and in anomalistic cases, and what information/tools they miss.*
Information about how different uncertainties and risks are evaluated and dealt with in decision-making. Information about costs arising from lacking/poor information, and potential savings/income if the information is improved.

Topic 3: Provision of S2S information and development of a decision support tool (DST)

22. Ideally, what sorts of S2S data/information (including format) would you need to make better decisions?

22.1. How can such information be rendered trustworthy for justifying decisions in your company?
22.2. How should it be provided in order to be usable (i.e., not only useful, but actually being used)? E.g., raw or processed data of essential climate variables, energy indicators based on climate variables, or both? On-line interface to visually browse data, only option to download data, or both?
22.3. Which type of support do you expect to be provided to be able to use the S2S forecasts (e.g., published relevant past case studies, monthly outlook with predictions and assessment of past month performance, workshops, webinars, technical support team, information about climate drivers for a particular prediction, DST backtesting option, etc.)?

23. The project will develop a decision support tool (DST) that will be available on-line providing a year and a half of operational S2S predictions. How can the performance of the DST be assessed with a base in real-life decision-makings in your companies? What would you perceive as a success criteria for such a tool?

24. What national or European policies could aid the uptake of S2S forecasts and the DST?[1]

25. [If applicable]. We already have a representative from your institution in the project. If there are other representatives you think should be involved/consulted in the development of the DST, please inform us.

Expected output data: *Information about how S2S information best can be provided, how the decision support tool can best be developed to become usable, and how its performance can be assessed.*

Closing remarks

26. Is it anything else you think we should know about, or other persons we should speak with?

[1] This question was asked to collect information for T6.3 but it is not in the scope of the analysis of this deliverable (D2.1).

5.2 Appendix II- Consent form

Informed Consent Form

Please read this document carefully.

Purpose

The purpose of the interview is to help mapping the user needs in the S2S4E project. We would like your consent to sound record and transcribe the interview for project-specific research purposes.

Information collection

All data collection and storage will comply with EU GDPR regulations. We will ask you a set of questions (similar for all interviews). The sound record will be transcribed after the interview. All digital files (sound recording and transcript) will be encrypted and stored on a secure server. When the project ends the files will be deleted within one year.

Confidentiality

Participation in this study is voluntary. By signing this form, you are giving your permission to S2S4E research partners to use information provided by you for research purposes. This study is strictly restricted to research; all information will remain confidential.

At no time will your name or any other identification be used in any form.

As you are participating in a study for an ongoing research project, any information you acquire through the project is confidential and proprietary. By signing this form, you agree not to disclose any information regarding this study/research project, apart from publicly available information.

Freedom to withdraw

You are free to withdraw your consent to the study and discontinue participation at any time without further notice. The files will then be deleted immediately.

Compensation

Other than access to public outputs from the project, we will provide no compensation for your services rendered in this evaluation.

Keep me updated! Tick the box if you wish to receive updates from the project ☐

Please indicate your agreement by signing;

I have read and understood the information on this form, and agree to participate in this study.

Name: _________________________________

Signature: _________________________________

Date: _______________

Thanks!

We appreciate your cooperation!

5.3 Appendix III – Already defined case studies

The figures are made using ERA-Interim reanalysis (Dee et al., 2011).

Case study 1: Winter 2016-2017, cold spell over Europe and lower than normal wind and hydropower generation

Period / Year	17 – 23 Jan, 2017
Time horizon	Sub-seasonal
Region	Europe/France-Germany
Implications	Hydro and wind power generation, demand

With the increase in the share of electricity generated by renewable energy sources and the rapid reduction of generation capacity from incumbent energy sources, the European energy system has become highly sensitive towards extreme weather events. Cold events in winter have strong impacts on the power system. They are often due to blocking events, combining cold temperatures, no precipitation and low wind speed, then implying large electricity demand, and lower than usual hydro and wind power generation. In France, under the national regulation authority request, utilities had to stop several nuclear reactors to carefully check some components. The total available generation capacity in France was then significantly decreased. Electricity demand and power generation forecasts were then very important to assess the risks on the French and European systems. Several options can be activated in such situations, but need as accurate as possible forecasts to optimize decision and take the best options. In that period (17 – 23 Jan, 2017) a cold wave over Europe created a combination of large increase in electricity demand and lower than normal renewable energy supply (Figure 22 and Figure 23).

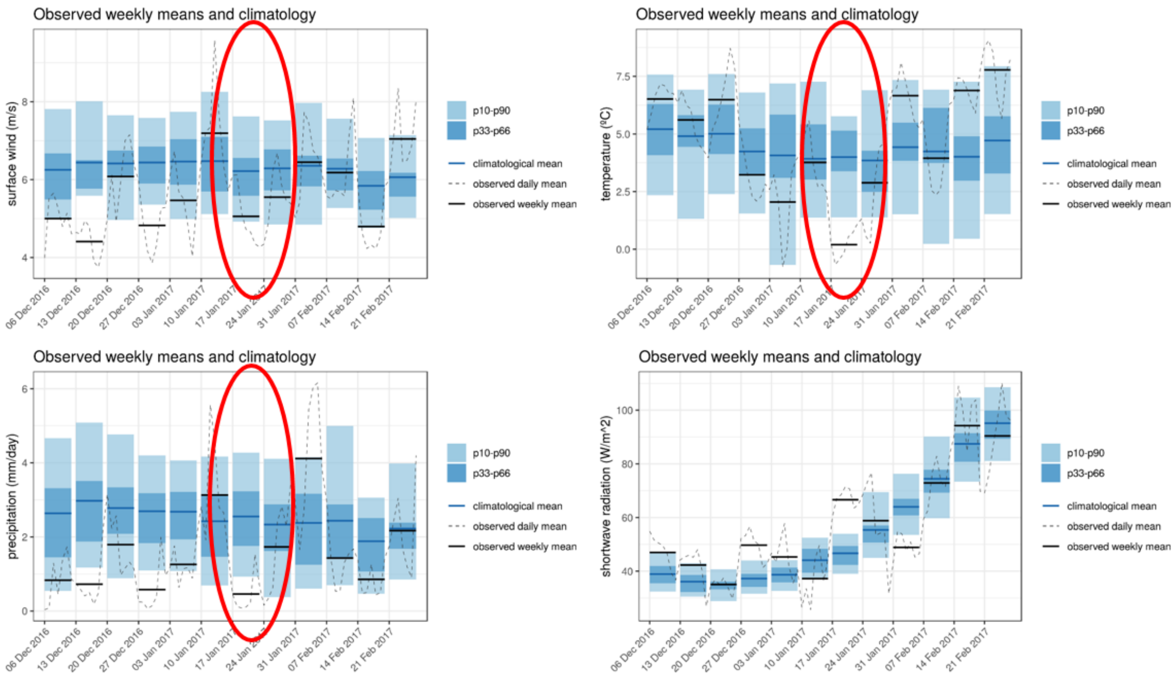

Figure 22: Observed weekly means (black lines) and climatology means (in blue) for surface wind speed (upper panel-left), temperature (upper panel-right), precipitation (lower panel-left) and solar radiation (lower panel-right).

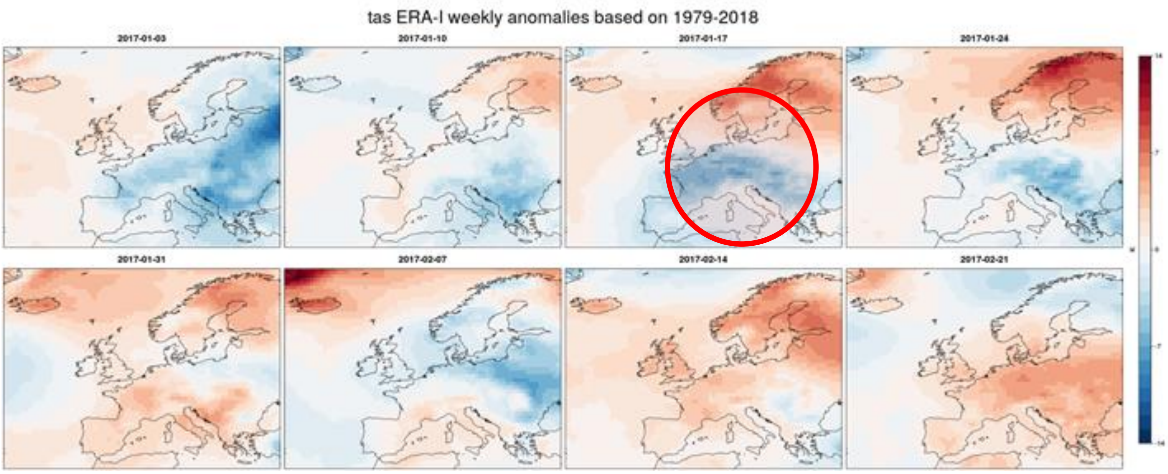

Figure 23: Europe temperature weekly anomalies, from January 3rth to February 21. Low temperature is observed for the week of January 17, 2017, mainly in France and Germany.

Case study 2: July 2013, Germany. Large electricity demand, higher than normal solar generation and low precipitation rates.

Period / Year	23 – 29 Jul, 2013
Time horizon	Sub-seasonal
Region	Germany
Implications	Hydro, wind, solar power generation, demand

With nearly 39 GW of installed photovoltaic capacity, periods of high solar radiation during summer in Germany may shift the energy mix considerably. During these periods of elevated solar generation, expensive conventional power plants may be shut down, with a downturn in the energy trading market as a consequence. In this context, coal power plants are typically used as backup to ensure security of supply. In Germany, coal supply is largely based on hydro transport which is dependent on river navigability associated with precipitation levels. In this specific case, the very low precipitation levels, may, of prolonged, restrict transportation capacity on major waterways like the Rhine and Neckar rivers. This is of particular relevance for utilities that transport transports coal mainly per barge to power plants along the aforementioned rivers for conventional power supply.

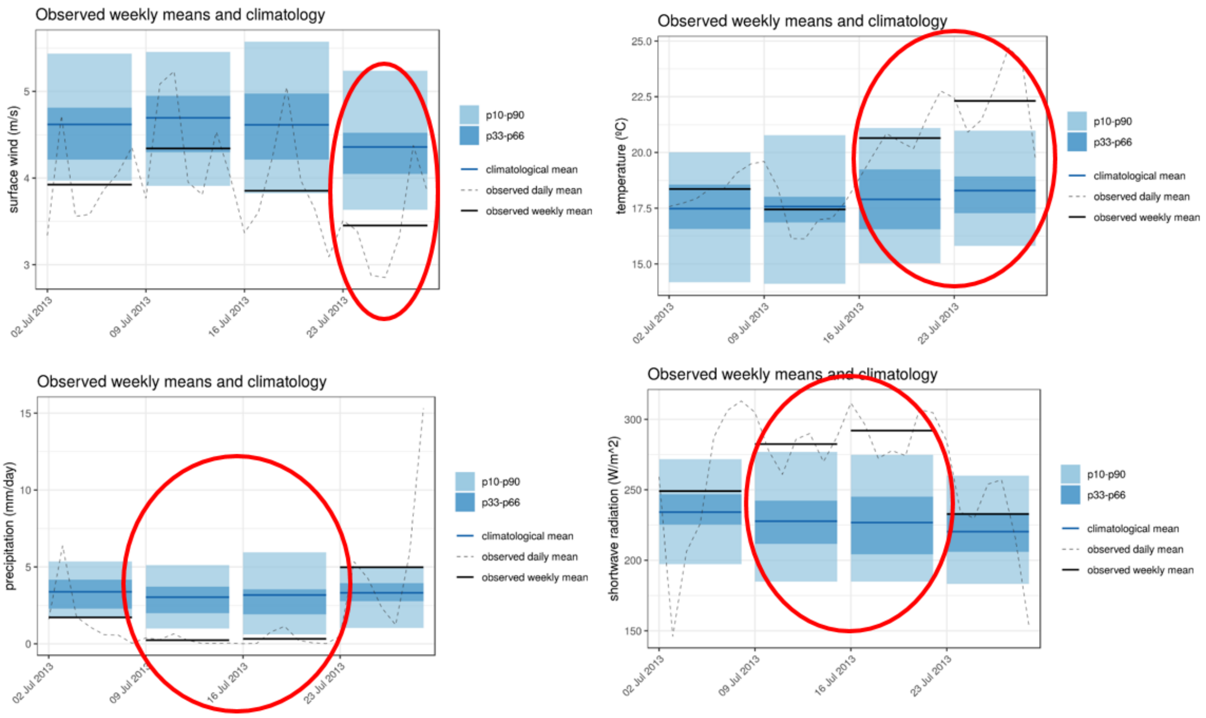

Figure 24: Observed weekly means (black lines) and climatology means (in blue) for surface wind speed (upper panel-left), temperature (upper panel-right), precipitation (lower panel-left) and solar radiation (lower panel-right). By the week of July 23, 2013, high temperature, high solar radiation and low surface wind speed means are observed compared to historical climatological mean.

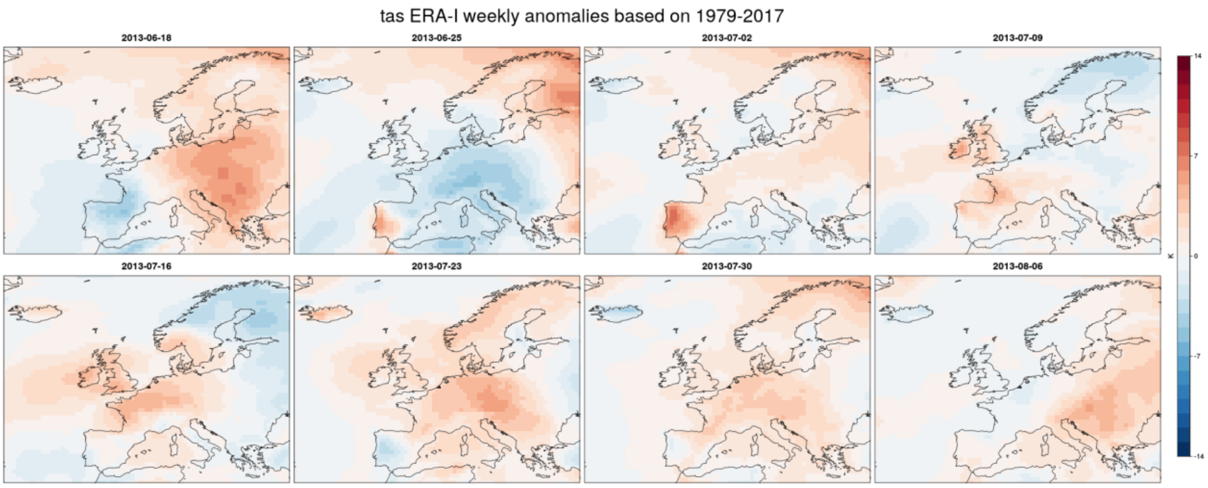

Figure 25: Europe temperature weekly anomalies. High temperature is observed for the week of July 23, 2013, mainly in central Europe.

Case study 3: September 2016, Heat wave and wind drought in Spain.

Period / Year	30 Aug – 05 Sept, 2016
Time horizon	Sub-seasonal
Region	Spain
Implications	Wind power generation and demand

According to the Spanish TSO, in 2016 the installed wind power capacity represented 22.8% of the total capacity for electricity generation in Spain, and wind energy supplied 19.2% of the demand. This high level of wind power penetration that can have a significant impact on the energy market in periods with lower than normal wind power output especially if it is combined with a heat wave as it was during this case study.

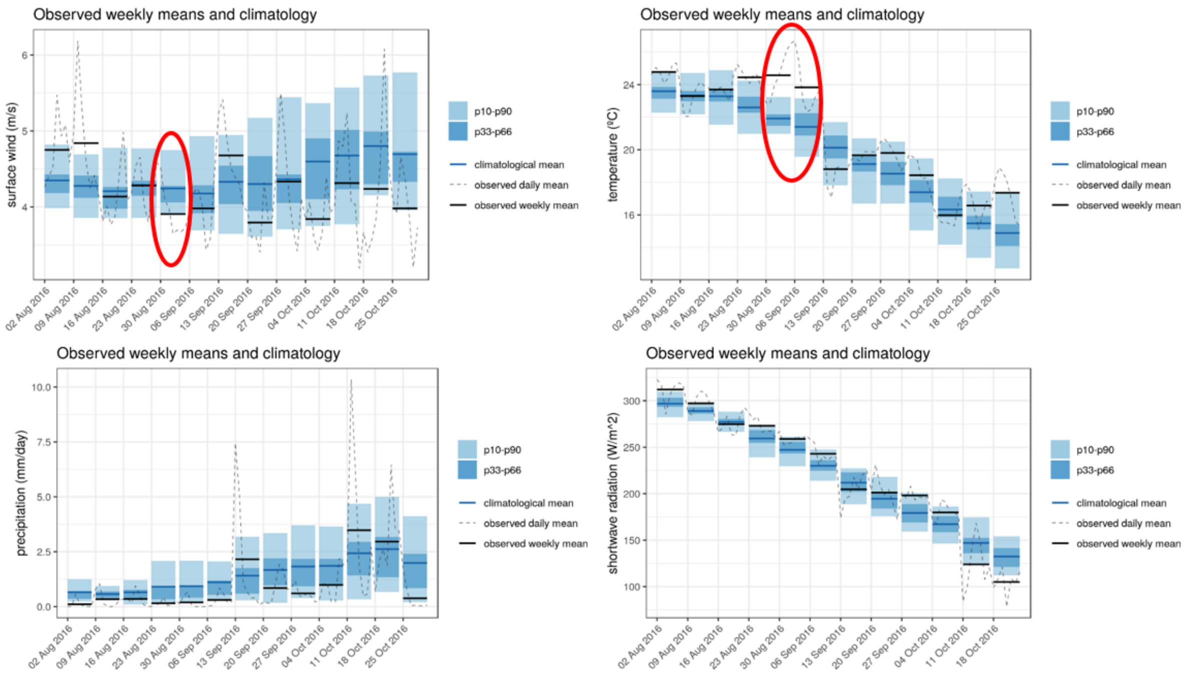

Figure 26: Observed weekly means (black lines) and climatology means (in blue) for surface wind speed (upper panel-left), temperature (upper panel-right), precipitation (lower panel-left) and solar radiation (lower panel-right).

At the beginning of September 2016, high temperature and low surface wind speed means are observed compared to historical climatological mean in Spain.

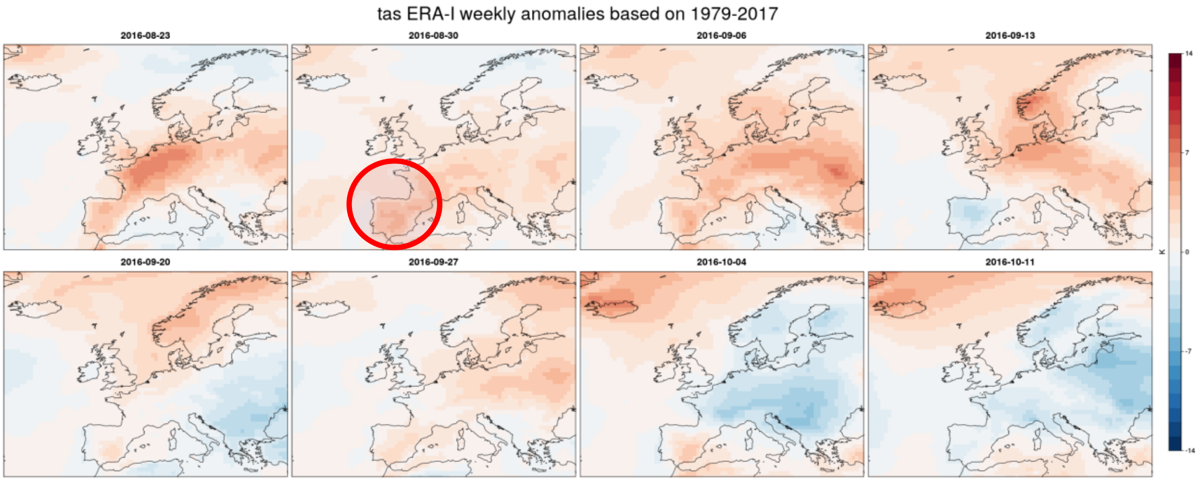

Figure 27: Europe temperature weekly anomalies, from August 23rd to October 11th, 2016. High temperature is observed for the week of August 30- September 5th, 2016, mainly in Spain.

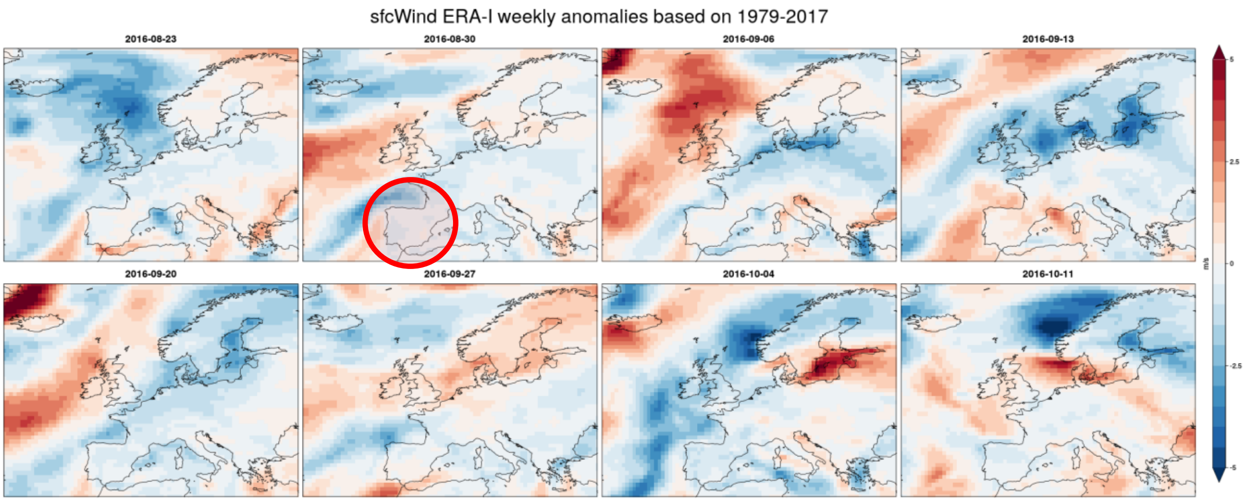

Figure 28: Europe wind speed weekly anomalies, from August 23rd to October 11th, 2016. Low wind speed is observed for the week of August 30- September 5th, 2016, mainly in Spain

Case study 4: Spring flood in Sweden, May-July 2015.

Period / Year	May-Jul, 2015
Time horizon	Seasonal
Region	Sweden
Implications	Hydro

In July 2015, a combined snowmelt and rain caused a lot of unproductive release of reservoir water in Umeälven. The reservoir was not managed appropriately without releasing enough water earlier in June/July. This was due to inaccurate hydrological forecasts that predicted a lot of remaining snow for melting. In the first weeks of July, the melting runoff stopped due to low temperatures; however snow was still available which flowed to the reservoir later. The lack of accurate information about snow availability resulted in a significant economic loss for hydropower generators. This case study investigate to which extend improved hydro meteorological forecasts offered from DST could have reduced the water loss during the spill event. The case study will be developed in collaboration with a Sweden's hydropower producer, and with the coordinator of the production and reservoir management in rivers.

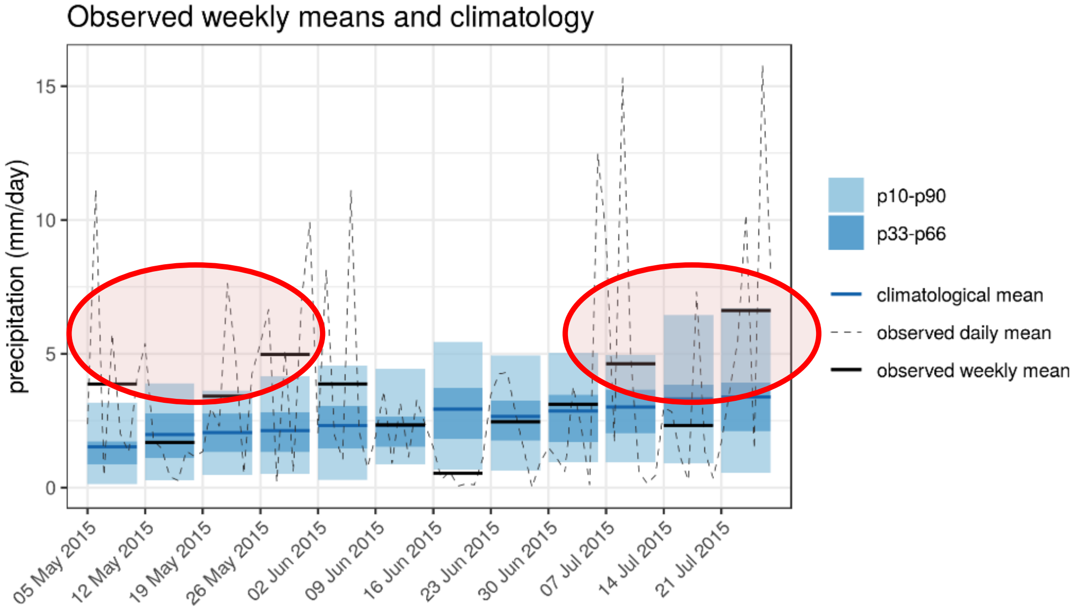

Figure 29: High precipitation weekly means were observed, by the months of May and July, 2015, compared historical climatological mean.

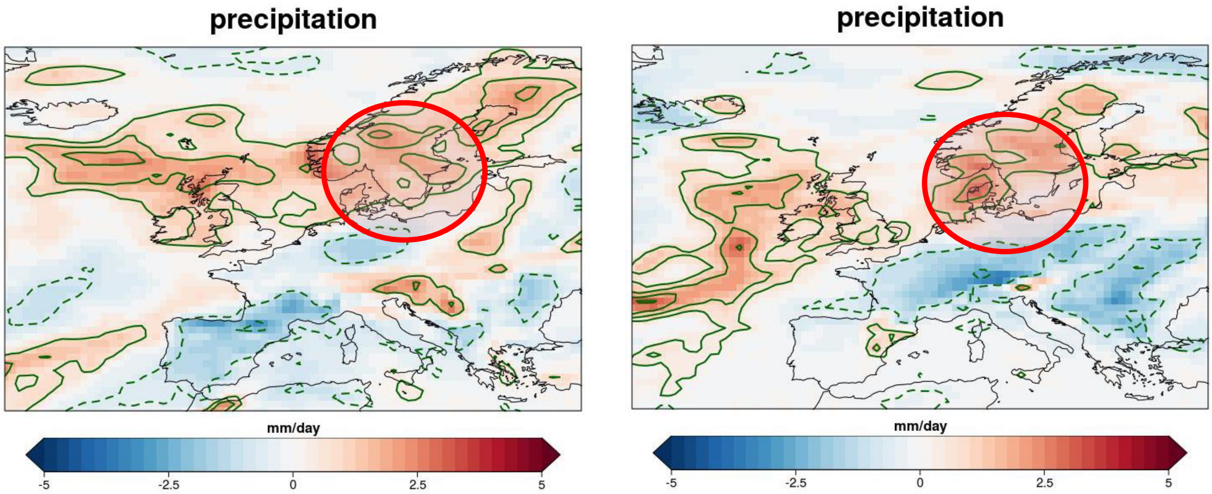

Figure 30: Sweden high precipitation anomalies during May (left figure) and July 2015 (right figure).