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Co-production pathway of an end-to-end climate service for improved decision-making in the wine sector

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HIGHLIGHTS

- There is a need for collaborative modes of engagement between scientists and users.
- The MED-GOLD Dashboard is a success story of a climate service for the wine sector.
- Climate service co-production can support agriculture adaptation to climate change.
- Enhanced co-production processes can guide the standardization of climate services.

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ABSTRACT

Climate services are one of the tools that can support the agriculture sector to address the impacts of climate change on agricultural production systems, not only considering climatic aspects but also social needs. This work describes the knowledge co-production journey of the EU-funded project MED-GOLD to create an end-to-end climate service for wine sector users. In this work, co-production is understood as an iterative, interactive and collaborative process among an interdisciplinary group of scientists and users that were engaged, involved, and empowered. The co-production process included activities to raise awareness on the vulnerability of grape and wine production to climate change, exchange knowledge between climate service providers and users, and co-develop customised climate services, such as the MED-GOLD Dashboard. Lessons learned are that repeated interaction between scientists and users allow to better frame research questions, jointly decide how to address these questions, and test the outcomes with feedback from real-world decision-makers. Furthermore, having a user who co-developed the service and helped assess its added value was key to ensure that it could truly inform decision-making needs and to promote its broader uptake by the wine sector community. Although the MED-GOLD Dashboard constitutes the most tangible result of this collaboration, the outcomes of co-production also encompass the joint learning process, the shared sense of ownership, and the co-creation of new knowledge between scientists and stakeholders. Nevertheless, further research will be needed to understand how the knowledge coproduced with a single user can be scaled up to users with other profiles and requirements.

Practical Implications

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Climate services, understood as the provision of climate information for use in decision-making, have been created to support societal needs for adaptation and mitigation. However, in order to be salient, credible, and legitimate, climate services need to be co-produced involving all the relevant actors in the process. This study describes the modes of engagement and collaborative research used for the co-production of a climate service aimed at the wine sector in the context of the European project MED-GOLD. During the co-production process, the repeated interaction between an interdisciplinary group of scientists (i.e. natural scientists, social scientists, technology developers, science communication experts) and wine sector users, allowed partners to frame the research questions together, decide how to answer them, and test the results. Involving the users is necessary to bring together the supply and the demand side, resulting in a more effective provision of climate services. Thus, knowledge exchange through a number of participatory activities (workshops, focus groups, user-provider interactions) allowed for an initial identification of the users' needs, followed by the exercise of matching the users' expectations with what scientists were able to deliver, and continued with a joint definition of how climate services for the wine sector should look like.

The process continued with the co-development of the MED-GOLD Dashboard, an easy-to-use climate service tool aimed at the wine sector and other agri-food systems. It provides access to information on past climate and predictions of the future climate at different time scales in the form of visualisations and data that users can download. Although the Dashboard was not planned at the beginning of the project, it soon became obvious that a tool with a visualisation component was needed for non-experts in climate science to be able to use the project results more easily. This evidences how the availability of climate data is not enough for this data to be actually used. In addition, it must be communicated and delivered in a suitable way to be understood, accepted, and used. Indeed, only a service that proves useful and practical for users, and that is tested with them, can have a role in decision-making processes, meaningfully informing decisions that require consideration of past, current or future climate changes.

Overall, this work has set the basis for a successful collaborative mode of engagement and research in the co-production of climate services for the wine sector. This foothold, established in the framework of the MED-GOLD project, can serve as useful guidance in the standardisation of future climate services' components, which is needed to better support sectoral risk management in the agriculture and other climate-sensitive sectors.

Data availability

Data will be made available on request.

Introduction

Farmers are used to dealing with risk on a daily basis, which is in part due to the uncertainty of present and future weather and climate conditions. While agriculture involves a great deal of planning - organisation of labour, tools, seeds, inputs, capital, and land preparation - there is also plenty of room, and often need, for improvisation in the execution of plans, as well as deviations from them (Batterbury, 1996). Despite their experience in coping with climate uncertainty, the increase in variability due to climate change has put farmers' adaptive capacities at stake (Crane et al., 2011). Climate services, understood as the provision of climate information and knowledge for use in decision making that support adaptation and mitigation (Hewitt and Stone, 2021), are one of the tools that can support the agriculture sector in identifying and adequately addressing the expected changes in climate and their impacts on agricultural production systems (Born et al., 2021; Falloon et al., 2018; Hansen et al., 2019; Mihailescu and Bruno-Soares, 2020). However, for adaptation in agriculture to be successful, it needs to be effective not only in climate and environmental terms, but also from the perspective of the social needs of individuals and communities who perform agricultural management.

New climate data and services are increasingly being produced by the climate research community; yet, it remains unclear how successful they are in connecting with the knowledge and needs of stakeholders and supporting their decision-making (Bojovic et al., 2021). Literature findings suggest that climate services are still based on broad assumptions about stakeholders' needs and, despite promising better decision-making, they mainly focus on delivering better data (Findlater et al., 2021). This links directly to the way climate services are produced and delivered, which has been traditionally considered a natural science endeavour. However, the use of climate information is a social science problem, and thus, requires the pluralism and diversity that participatory methodologies from the social sciences and humanities offer, in order to better connect science and society (Meadow et al., 2015; Palsson et al., 2013; Pulkkinen et al., 2022).

Knowledge co-production has recently become a common theme in climate services (Bojovic et al., 2021). However, in spite of the number of activities developed, there is still no broadly accepted understanding of what the term 'co-production' means in practice, which has resulted in a heterogeneous picture (Bremer et al., 2019; Lemos et al., 2018; Norström et al., 2020; Vincent et al., 2018). The importance of bringing scientists and stakeholders together to co-develop new knowledge that produces practical outcomes calls for truly interdisciplinary research teams able to engage with non-academic actors (Baer et al., 2019). It also involves choosing the most suitable ways to engage with these actors and defining their contribution based on an understanding of their interests, needs and backgrounds (Jolibert and Wesselink, 2012). In the context of research and innovation projects, a full inclusion of non-academic stakeholders (e.g. as partners in the project) may be a good solution in certain cases. In other cases, alternative engagement modes could be more adequate to ensure higher flexibility of involvement for non-academic stakeholders, such as the provision of seed money or compensation for the time spent (Baer et al., 2019).

A clear definition of the role of researchers and non-academic stakeholders from the beginning of the co-production process allows the creation of a suitable space where both can interact and contribute on equal terms, without power imbalances (O`Brien and Sygna, 2013; Reed et al., 2018). However, these interactions can be superficial and insufficient (Pregernig, 2006) if researchers lack the experience, resources or clear guidance on best practices in collaborative knowledge co-production (Findlater et al., 2021). This calls for the involvement of actors with different expertise in the research conceptualisation, implementation, monitoring and evaluation. In this sense, efforts to develop high-level recommendations for researcher-stakeholder interactions during the co-production process have emerged in the last years (Buontempo et al., 2018), along with more concrete guidance on how to conduct participatory activities that integrate scientific and other knowledge sources (Carter et al., 2019; Hewitt et al., 2017; WMO, 2018).

In the framework of the EU-funded project MED-GOLD - *Turning climate-related information into added value for traditional MEDiterranean Grape, Olive and Durum wheat food systems* (https://www.med-gold.eu/), intensive and collaborative activities have been applied resulting in the co-production of usable science. Even though the project has developed tools for different sectors, this paper presents the co-production pathway followed by a transdisciplinary team of natural scientists, social scientists, technology developers and users involved in the creation of an end-to-end climate service for improved decision-making in the grape and wine sector. To the authors' consideration, it is the first time this kind of knowledge has been genuinely coproduced considering a variety of climate information sources, decisions, and time scales relevant to this sector. This pathway has different stages: raising awareness on the vulnerability of grape and wine production to climate change, exchanging knowledge between project researchers and stakeholders, and co-developing a dashboard tailored to the climate change adaptation needs of vineyard managers and wine producers.

Indeed, dashboards for data visualisation are commonly used tools, although their design and context of application are considerably different from other exploratory visualisation tools (Sarikaya et al., 2018). Defined by Wexler et al. (2017) as '*visual displays of data used to monitor conditions and/or facilitate understanding*', dashboards have evolved from single-view reporting screens to interactive interfaces with multiple views and purposes, including not only traditional monitoring and decision support, but also communication, learning and motivation. These characteristics have made them ubiquitous, employed by nearly every industry and organisation providing services (Sarikaya et al., 2018). In the fields of Earth Observation and climate services, dashboards are often used to support users' strategic and operational decision-making (Bastidas et al., 2021; eShape, 2022), including the provision of agro-climatic information for different crops, such as grapes (Marcos-Matamoros et al., 2020a, Marcos-Matamoros et al., 2020b).

The following sections 2–5 document the different stages that the MED-GOLD project has gone through and the assumptions made in all of these stages to attain the final objective of providing a comprehensive climate service to wine sector users. Although the MED-GOLD Dashboard can be seen as the final product developed in the project, this journey goes beyond the co-production of a mere platform. It also encompasses the joint learning process, the empowerment that generates a sense of shared ownership, and the co-creation of new knowledge between scientists and stakeholders. Besides, the MED-GOLD dashboard is delivered along other elements that are part of the climate service, such as user guides, infosheets or capacity-building sessions to capacitate users to benefit from the service. This aligns with the notion that facilitating an exchange between different viewpoints may be more important for solving real-world problems than the produced outcomes themselves (Farrell et al., 2001; Glass et al., 2013).

Knowledge co-production approach

An effective co-production process is required to transform climate data and information into added value for users. Thus, by building on the World Meteorological Organisation's Guidance on Good Practices for Climate Services User Engagement (WMO, 2018), and incorporating insights from social sciences and humanities, MED-GOLD applied a co-production approach that helped establish a smooth and effective interface between scientists and users (Bojovic et al., 2021; Bruno-Soares and Buontempo, 2019; Hewitt et al., 2017).

Within the framework of the project, co-production is understood as an iterative, interactive and collaborative process that encompasses engagement, involvement and empowerment stages (Fig. 1). Engagement with users was achieved by raising awareness on the vulnerability of grape and wine production to climate change, and by showcasing how climate information and services could help support sectoral adaptation (see section 3). Researchers and non-academic stakeholders were subsequently involved in a more profound dialogue and knowledge exchange, where they framed concrete problems and discussed the potential solutions (see section 4). In this case, the stakeholder involved was the project partner SOGRAPE, the largest wine company of Portugal, which manages vineyards in seven national wine regions and in four additional countries across the globe. Empowerment of both researcher and user groups was then achieved through the co-development stage, where climate information was tailored to the needs for climate adaptation of wine sector users, and the MED-GOLD Dashboard represented the outcome of this process (see section 5). It is important to highlight that, in this context, co-production integrates both the process and the product or service (Borie et al., 2019; Daniels et al., 2020; Vincent et al., 2018).

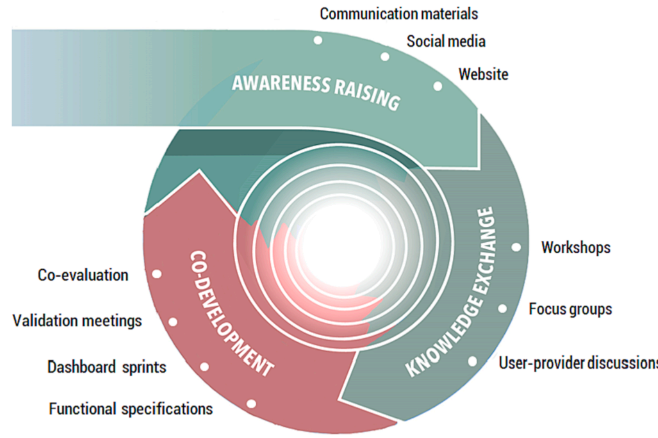

Fig. 1. Knowledge co-production approach applied for the development of the MED-GOLD Dashboard, consisting of awareness raising (engagement), knowledge exchange (involvement) and co-development of climate services (empowerment) for supporting the adaptation of the grape and wine sector to climate change (adapted from Bojovic et al., 2021).

Raising awareness on the vulnerability of grape and wine production to climate change

Without rigorous engagement, users may be unable to articulate their needs, identify how climate information might improve decisions and integrate it with other information (Findlater et al., 2021). In the context of the project, engagement was achieved through various communication channels for raising awareness about available or emerging climate information and services. In this sense, it is important that stakeholders in the grape and wine sector understand that what was considered 'normal' in the past is currently changing, and that the traditional knowledge that used to guide agricultural practices is no longer working under the new 'normal' situation brought up by climate change. The project website, social media (Twitter, YouTube), and sector-specific communication materials (e.g. info sheets, promotional videos) were useful channels to raise awareness at the beginning of the project. However, engagement continued throughout the whole co-production process, as the knowledge exchange and co-development of new knowledge allowed for more customised material to be generated for sharing and engaging with new stakeholders external to the project.

Knowledge exchange between climate service providers and users

Interactions for knowledge exchange between scientists and users occurred throughout the project and involved different types of activities. These included thematic focus groups to define the user needs, an internal participatory workshop to match the expectations of climate service providers and users, and regular meetings with discussions between users and providers that helped define the characteristics of the climate service developed in the project.

Climate-related information needs for decision-making in the wine sector

Viticulture is a complex and dynamic system, where grape phenology, quality and yield strongly depend on the regional climate (Cunha and Richter, 2016; Fraga et al., 2014; Ramos et al., 2008). Among the expected impacts of climate change on vineyards are the acceleration of phenological processes of the grapevine, the advancement of grape maturity and harvest dates, as well as changes in the frequency of extreme events, such as droughts (Ollat et al., 2016; Schultz and Jones, 2010). Thus, the most common decisions likely to be affected by climate change relate to the choice of grape varieties, clones and rootstocks, vine load, canopy management, pest and disease management, choice of cultivation areas and use of decision support tools (Mihailescu and Bruno-Soares, 2020).

Prior to developing climate services tailored to the agriculture sector, it is critical to identify what companies need to know about the future weather and climate, and how they want to receive this information. For that purpose, four focus groups addressing different themes (strategy, viticulture management, oenological management and stock management) were organised at the premises of the SOGRAPE wine company in Portugal. The focus group method was selected because it allows obtaining information from participants in a relaxed atmosphere. The activity involved 12 technical experts from different areas of the company, including the departments of oenology, viticulture, human resources, project management, hosting and public relations, innovation, quality and safety, property maintenance and general service. The questions used in the focus groups were jointly prepared by social scientists and the SOGRAPE partners involved in the project. The aim was to ascertain the key operational and strategic decision-making processes that could potentially benefit from the use of seasonal climate forecasts, long-term climate change projections and bioclimatic indices (based on both climate forecasts and projections).

These discussions revealed that the participating wine users face diverse challenges affecting several decision-making processes in their business, such as strategic decisions, and viticulture, oenological and stock management at different time scales (Fig. 2). More detailed information about these processes was provided in a previous study by Teixeira et al. (2019).

In the medium range (i.e. next 1–12 months), some of the challenges highlighted by the company's viticulture management department include pruning and canopy management, the planning of plant treatments, and the accurate setting of harvest dates. The need for optimising labour management, operational subcontracting and environmental protection was also noted. On the other hand, the oenological management department needs to plan maturation control and improve harvest efficiency.

Information on forecasts at seasonal timescales would allow vineyard managers to anticipate the best timing for vineyard operations and to schedule plant treatments with higher temporal precision. Another benefit of this information would be the earlier identification of time periods with high demand for labour and inputs. Seasonal forecasts can also help the oenological department identify likely moments for veraison and harvest, as well as to timely anticipate adverse conditions that could affect the vineyard and compromise the yield and quality of the wine. Finally, having information about climate conditions in the next months would allow the department of stock management to negotiate contracts with suppliers in a timely manner, obtain better prices, and acquire products in advance, thus avoiding limited product availability under climate risk conditions. Moreover, this would enable better planning of marketing and promotions for the next months, allowing the wine company to analyse key moments for launching promotional or new brand campaigns.

In terms of the long-term (i.e. next 20–100 years) challenges faced by the wine company, participants highlighted the purchase of new vineyards or the selection of future new locations. Other decisions mentioned were the choice of grape varieties and rootstocks, as well as the vineyard design (including aspects such as training system, row orientation, and the need for irrigation or drainage for decreasing soil erosion and the risk of landslides in slope vineyards).

Climate change projections provided by the project can support the identification of areas with suitable climate to meet production and quality goals in the next decades. Likewise, the adequate grape varieties and rootstocks that could match the expected climate can be identified. This long-term information is also useful for anticipating future adverse climate conditions for the production of the current wine styles, which will most probably require a change in the company's strategy.

Matching the expectations of climate service producers and users

After the first interactions between climate information producers and users, it became obvious that some climate concepts were not understood in the same way by the different communities, which could cause misunderstanding and discrepancies. Because these discrepancies are often responsible for the lack of understanding between project scientists and users, its is key to clarify and agree on a common terminology from the beginning (Calmanti et al., 2021; Terrado et al., 2022a). To ensure mutual understanding and achieve a successful development of a climate service for the wine sector, an internal participatory workshop on user perspectives was organised in Brussels in February 2019. The internal workshop was attended by project partners, including both researchers and agriculture sector users, and aimed to agree on user-centred definitions of important concepts connected to the decision-making context of users. Concepts like 'reliability', which can have distinct connotations in different contexts and disciplines, were

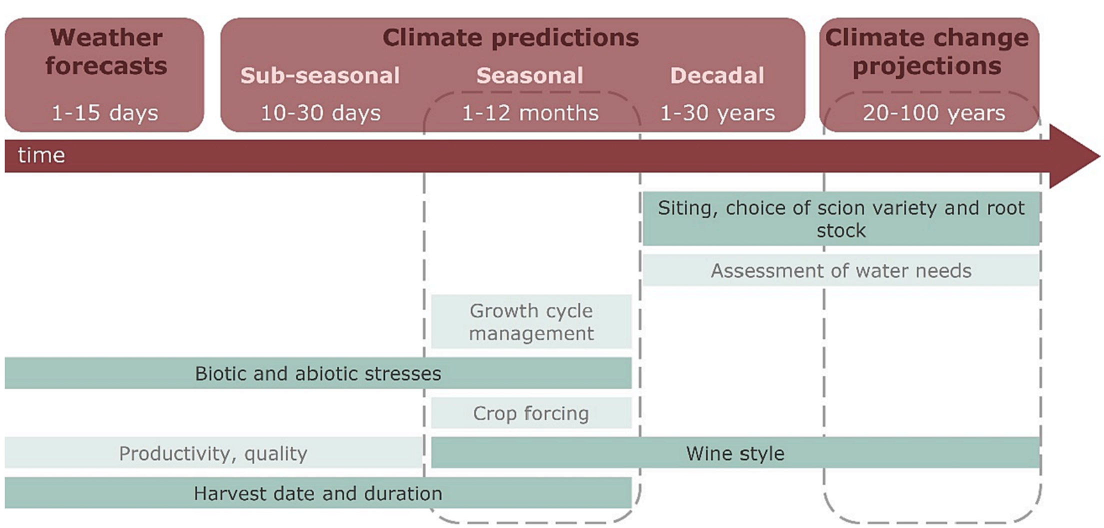

Fig. 2. Decisions made by the wine sector at different time scales (adapted from Gishen et al., 2016). Dark green squares indicate the decisions addressed during the project, at the seasonal and long-term time scales (dashed line). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

discussed. An example of this discrepancy is that, while for the wine user the term 'reliability' indicates a prediction that can be trusted, scientists understand it in a different way. For climate scientists a prediction is reliable when the predicted probability matches the frequency in which a situation has occurred in the past. That is, if the prediction gives a 60 % probability of rain for a particular season and region then, on average, the rain predicted in that season and region has occurred 60 out of 100 times in the past. Similar disparate interpretations occur with other terms, such as the 'skill' of climate predictions which, despite being a key concept to decide whether a particular prediction should be applied for decision-making, is unfamiliar to the stakeholder community.

A key conclusion arising from the workshop was that terminology is pivotal to the successful co-development of climate services. However, rather than sticking to the technical concepts used by scientists, it is imperative that such terminology is discussed and co-developed between stakeholders and scientists to allow a shared understanding of the key concepts relevant to stakeholders' decision-making. To that end, the project co-developed a glossary of terms that aimed to find a common ground between both communities that helped mature understanding and build trust. The glossary, which is available on the project website, also included examples to illustrate the term in the context of the target user. Like the other communication and dissemination materials developed by the project, the glossary was prepared in different languages (English, Italian, Spanish, French, Portuguese, and Greek). These findings are in agreement with previous studies suggesting that the usability of climate services is enhanced by defining an appropriate terminology and language matching those that the users are accustomed to (Miraz et al., 2016; Terrado et al., 2022a, Terrado et al., 2022b).

Picturing a climate service for the wine sector

Recurrent discussions between users and scientists were held throughout the project (e.g. in the annual General Assemblies and in regular meetings among partners organised to discuss the project's tasks and activities). In addition, a co-development workshop was organised at the premises of the SOGRAPE company in Portugal in May 2019 to discuss the climate service tool for the wine sector. The workshop was a follow-up from the previous focus groups and was again organised by social scientists and the SOGRAPE partners involved in the project. Participants were 12 decision-makers from different areas of the company – viticulture, oenology, hosting and public relations, human resources, real estate and maintenance, marketing, senior management, quality, and environment. Thanks to the previous facilitation work developed by the company members involved in the project, participants were already familiar with many of the concepts presented, which made the process highly effective.

Participants were presented with different visualisation options to display seasonal and longer-term climate information regarding essential climate variables (mean, maximum and minimum temperature, and precipitation), bioclimatic indicators (Growing season average temperature, Harvest total precipitation, Spring total precipitation, Number of heat stress days, and Warm spell duration index) and risk indices (sanitary risk index, and heat risk index). Bioclimatic indicators and risk indices were co-developed between project scientists and users (Dell'Aquila et al., in this issue).

During the workshop, users from the wine company expressed their preference to see the information displayed on a map, alongside tercile plots (or even percentiles, if possible) and accompanied by an explanatory text (Bruno Soares et al. 2019). Regarding the colour scales used in the visualisations, a blue-red colour gradient was selected for temperature-related information, a green–brown scale for precipitation-related information, and a 'traffic light' scale for risk indices. Despite not being colour blind friendly (Kaye et al., 2012), the 'traffic light' colour scale is still requested by users and frequently used to indicate climate risk levels (Mahony and Hulme, 2012; Morseletto, 2017), thus it was adopted in the project in spite of certain limitations. Furthermore, the option to access information gradually rather than all at once was preferred by users, since this offers them the possibility to decide what they want to see. This was highlighted by departments with lower technical profiles (e.g. hosting, human resources), who mentioned it could be overwhelming to have to select what they need from all the potentially available information.

Regarding seasonal forecasts, the users understood the fact that terciles provide a more reasonable representation of the prediction than percentiles. This is due to the limited number of ensemble members currently available, which could make the prediction look more uncertain if displayed using a complete set of percentiles. Therefore, users accepted the representation using three categories: above normal, normal, and below normal. In addition, they set a minimum threshold of 70 % hit-rate probability for a tercile to trigger a particular decision, assuming that the prediction has enough quality for decision-making (i.e. skilful prediction). Moreover, users highly valued the possibility to have information on essential climate variables up to six months ahead. Nevertheless, they found bioclimatic indicators to be more relevant for the operational activities of the company and proposed the calculation of additional indices like the total winter precipitation, cold spells and frost days (acknowledging that some of this information may be difficult to provide by the project).

Regarding climate projections, users were interested in the relative changes of variables and bioclimatic indicators (e.g. anomalies) rather than in absolute changes. In addition, they expressed their desire to have a layer of altimetry superimposed on the maps, since altitude plays an important role in the vegetative development of the grapevine at the local scale. Users also mentioned that altitude is a parameter to be considered for the coupling of the life cycles of pests and diseases with the grapevine's own growing cycle as well as the grapes' quality and fitness-for-use (Bruno Soares et al. 2019).

These initial interactions with users highlighted the need to enhance the understanding of climate knowledge by non-experts. As a result, specific dissemination materials targeted to the grape and wine community were co-developed to build capacity within the project's industrial partners, as well as support the engagement of external stakeholders. Targeted sector-specific dissemination materials included infosheets and webinars explaining topics such as climate predictions for the grape and wine sector, the time scales of climate services, and the interpretation of seasonal climate predictions for decision-making in agriculture (Terrado et al., 2020a, Terrado et al., 2020b; Vigo et al., 2018).

Co-development of the dashboard for the wine sector

At first, the project aimed to deliver climate information to the wine sector users through an Information and Communication Technology (ICT) platform. However, after several interactions to better understand users' needs, knowledge and expectations, it soon became obvious that a tool with a visualisation component was needed for non-experts in climate science to be able to more easily access the project results. Therefore, the co-development of the MED-GOLD Dashboard was carried out, continuing regular interactions, and obtaining feedback from users throughout the process.

The MED-GOLD Dashboard (www.dashboard.med-gold.eu) is an easy-to-use tool providing access to information on past climate and predictions of future climate at different time scales in the form of visualisations and data that users can download (Fig. 3). The tool is aimed at facilitating the adaptation of the wine sector, as well as other agri-food systems, to the impacts of climate change. Knowing in advance how the climate for the next months, seasons and years will be, will allow users to be better prepared and to adapt their management and planning strategies accordingly. Unlike other decision-support tools currently available for the wine sector, the Dashboard covers a time horizon that is rarely considered and goes beyond the next few days. These predictions can support other types of sectoral decisions in need

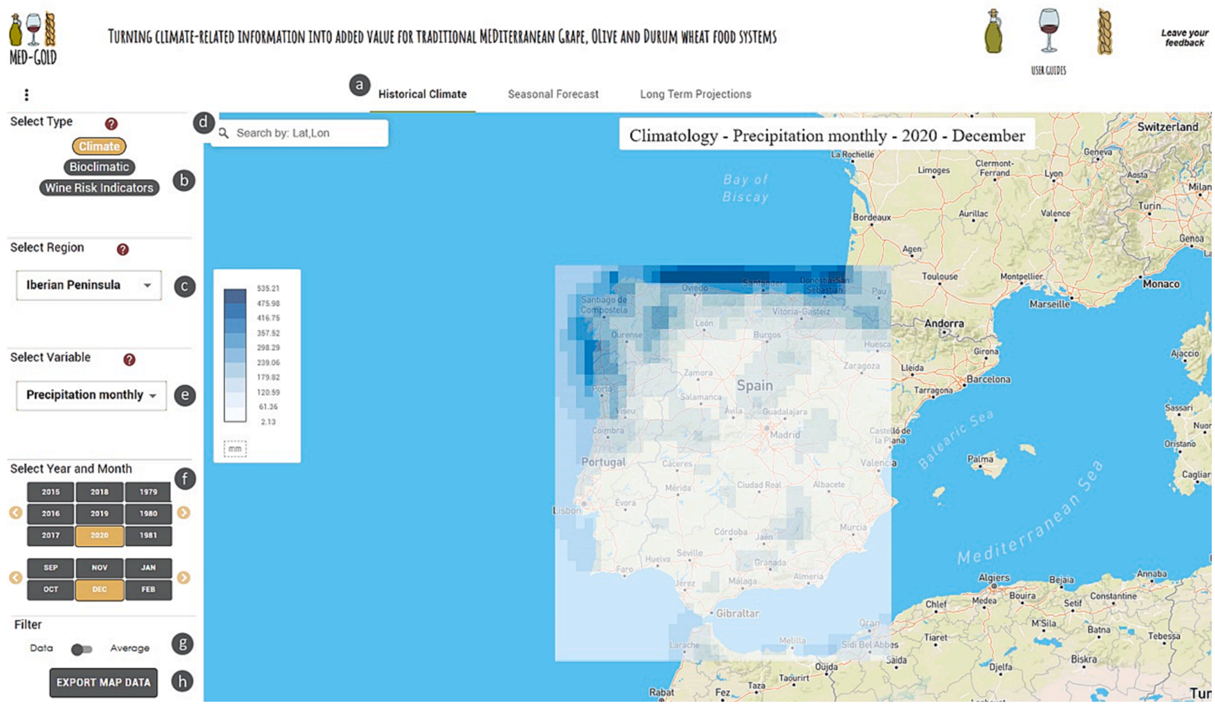

Fig. 3. The MED-GOLD dashboard for the grape and wine sector. The labels in the figure correspond to the following characteristics of the tool, in the order of selection by the user: (a) time scales: historical climate, seasonal forecast and long-term projections; (b) type of variables: climate, bioclimatic and wine risk indicators; (c) region of interest: Iberian Peninsula and Douro Valley; (d) location search; (e) variable of interest; (f) time period of interest; (g) other options or filters (according to the selected time scale): data, forecast skill and greenhouse gas emission scenario (intermediate or high); (h) export data.

for a larger anticipation. In addition, the Dashboard not only provides information on climate variables but also includes bioclimatic indices and risk indicators related to sectoral impacts and co-produced with wine sector users. Along this information, the tool also provides an indication of the prediction quality, which represents a level of transparency usually not covered in other tools.

During the dashboard's co-development phase, the collection of users' feedback was done in an iterative way and was divided in different stages: the co-development of a 'master' document with the description of the functional specifications of the platform; the organisation of 'dashboard sprints' to bring together scientific partners and users in periodic online meetings; virtual validation meetings to introduce the platform to representatives from the business company not directly involved in the development of the tool; and a co-evaluation of the service to assess its added value for the SOGRAPE company as well as for the wider wine industry. These four stages are summarised in the following sections, while a more detailed description can be found in Marcos-Matamoros et al. (2020c).

Definition of the functional specifications of the MED-GOLD Dashboard

A shared 'master' document was created by the technical developers of the Dashboard together with the SOGRAPE R&D department to enable an exchange of ideas, doubts and expectations among scientific partners and the user, leading to the consolidation of the features of the wine pilot service. The main aspects addressed in the master document included the following:

- Overall structure of the dashboard, including the main tabs: *Historical Climate* with information for the past and near present, *Seasonal Forecasts* with forecasts for the next months, and *Long-Term Projections* showing future scenarios until the end of the 21st century
- A list of the essential climate variables, bioclimatic indicators that take into account the climate and phenology of the vine, and compound risk indices that show if the vine is under risk from diseases or heat
- Geographical area covered (in the first release of the tool, the Iberian Peninsula was covered, with a zoom on the Douro Valley in Portugal)
- Main features of the interactive maps and time charts
- Adopted colour palettes
- Format for exporting figures and data
- Climate data sources: ERA5 for observations (resolution 30 km, period 1979–2019; Hersbach et al., 2020); PTHRES data for a zoom over the Douro Valley region, which was explicitly requested by the industrial partner (resolution 1 km, period 1951–2015; Fonseca and Santos, 2017); ECMWF SEAS5 data for seasonal forecasts (1 degree; Johnson et al., 2019); Euro-Cordex data for long-term predictions, zoomed over the Douro Valley (0.11 degrees).

Dashboard sprints

The Dashboard sprints were internal meetings introduced as a way to bring together the scientific partners and dashboard developers with users in periodic online meetings organised every-two weeks. During these meetings, developers presented the different elements of the Dashboard and received feedback, mainly from users but also from the rest of the consortium.

The meetings followed the main guidelines of the broader Scrum framework for the development of innovations and complex products (Schwaber and Sutherland, 2017). Thus, a product backlog was prepared by the platform's developer on the basis of the master document with the functional specifications listed in section 5.1. Then, the industrial partner played the role of the product owner and continuously indicated the priorities for the implementation of new features to best achieve the goals of the development of the platform. In addition, a development team provided support as specific needs emerged during the development phase, together with climate and social scientists and communication experts, who provided advice on issues related to their background knowledge. Finally, the Scrum Master ensured that the goals of the development were understood by every-one in the team, facilitating the overall process and supporting the team in understanding the needs as they evolved during the development process. An internal ticketing system was implemented to allow the consortium to regularly report bugs in the platform, therefore facilitating the testing tasks of developers.

The feedback obtained in the Dashboard sprints was ingested by developers, who were in charge of implementing the agreed suggestions and presenting the new changes in the following Dashboard sprint meeting. This process helped to ensure that all the developments performed followed as closely as possible the expectations of the users. At the same time, it allowed users to get familiar with the tool and become independent in promoting its usage to the wider community of wine sector stakeholders. This contributed to users' empowerment, a process that generates a sense of shared ownership of the climate service, since responsibilities are redistributed among all the participants (Bojovic et al., 2021; Mitchell et al., 2015).

User validation and reporting during the platform improvement phase

Once a beta-version of the tool was developed, virtual meetings conducted by SOGRAPE were held to introduce the MED-GOLD Dashboard to representatives from different operational departments of the wine company that were not directly involved in its development (i.e. did not participate in previous workshops). These meetings were run for around 1 h with a small number of users, typically 1–3 at a time, who were asked to share their screen while performing a number of tasks that were verbally requested. A total of 10 SOGRAPE users participated in the meetings, which were aimed to collect independent feedback from real-world decision-makers for further testing and improvement.

Each session followed a format that drove the user interaction with the Dashboard. First, users were requested to try the dashboard without any guidance, looking for information that could be of interest for them. The session host would only intervene in case users were stuck at some point during this phase. In a second step, the host directed the users to try those features they had missed in the first step and asked them how hard or easy it was for them to understand the information presented on the dashboard. At the end of the session, the host encouraged the users to provide feedback about their overall experience with the tool. The aspects assessed were related to: (i) the perceived value of the tool for decision-making, (ii) presented content, and (iii) user experience with the usage of the tool, including visualisation and information architecture aspects (Table 1). Particular attention was placed on the difficulties faced and potential suggestions for improvement.

Users' feedback on the dashboard was overall very positive. All participants recognised that the tool would bring added value to their work and could support their decision-making, after some improvement. As the sessions included participants with different profiles (i.e. training, age, familiarity with information and communication technologies, and previous contact with climate services tools), their interaction with the dashboard differed. Most users recognised that without assistance they would have not been able to navigate the dashboard on first contact and retrieve the information needed. They were particularly unanimous regarding the lack of on-screen guidance and clarification of terms, features, abbreviations, and acronyms used, many of which were completely alien to them.

Several users also noted the importance of being able to export maps and data in user-familiar formats (e.g. JPEG, PNG, CSV, Excel), as well as the presence of recurrent navigation and map-loading problems. In addition, the need for a minimum forecast probability threshold of 70 % for triggering a user's action was raised again, something that was already highlighted in the previous focus groups and co-development workshop (Bruno-Soares et al., 2019; Teixeira et al., 2019). At the end of each session, the users reported being more comfortable with the tool, evidencing that some prior training or guidance are needed before being able to use it, something that could limit the reach of the Dashboard to users without prior experience in climate tools and services.

The feedback provided by users was addressed in the final release of the tool to the extent possible (Fig. 3). Thus, to enhance the user experience with the dashboard (comments 1–3 and 10 in Table 1), the selection panel (initially in the top bar) was arranged as a sidebar based on

Table 1
Comments mentioned by more than one participant in the virtual meetings for validation and reporting of the beta-version of the MED-GOLD dashboard, grouped according to different aspects (n = 10). An exhaustive list of the comments received can be found in Marcos-Matamoros et al. (2020c).

Aspect	#	**Comment** (# mentions)
User experience (information architecture)	1	*When choosing options to visualise from the dropdown menus, a short caption explaining their meaning should pop-up as the cursor hovers over each option (especially abbreviations and acronyms). The same should happen when hovering above tab names (historical, seasonal and long-term) or type of data (7)*
	2	*Navigation is overall easy and intuitive; map updating is quick enough (3)*
	3	*The parameter panel needs to be better organised; it wastes too much space which would be better used to have more space for map viewing (2)*
	4	*Having the dashboard in English slows down [the process] and makes interpretation sometimes difficult. It would be much better if it was in Portuguese (2)*
User experience (map visualisation)	5	*Maps often take extremely long to load or do not load at all. There is a lot to be done in terms of susceptibility to user handling of the tool. It seems overly sensitive to movements or clicks on the map while loading. When zooming in, sometimes data colours disappear altogether and will not reappear when zooming out, especially in seasonal forecasts (3)*
	6	*Export GeoJSON and, particularly NetCDF, do not know what they are and how to use them. They should be available for those requiring them, but in a less prominent way than JPEG, PNG and other user-familiar formats (3)*
	7	*Many features and possibilities of the tool remain undiscoverable because of insufficient on-screen guidance (*e.g. *the chart that opens if a spot is clicked in the map). On-screen guidance must be everywhere (2)*
	8	*The map data-box that pops when a map grid cell is clicked is sometimes hard to close, requiring many clicks. It won't disappear when visualisation parameters are changed, creating wrong readings from the part of users (2)*
	9	*If in long term projections anomaly is reported in %, the legend caption needs to be changed [to reflect that] (2)*
	10	*The base map should not be displayed before all needed choices are made. After visualising a map, if choices are changed, the base map should redisplay again only after loading the visual data. Maintaining the map when parameters are changed is misleading (2)*
User experience (chart visualisation)	11	*Chart data series should also be exportable as data files (csv-type, ideally EXCEL) not just image formats (3)*
	12	*Bottom chart is confusing and hard to use when all months are displayed (3)*
	13	*When visualising seasonal forecasts, it should be possible to see the normal value at the same time (in the popup map data-box?) (2)*
Perceived value	14	*If forecast data are reliable, meaning being right more than 70 % of the time, it may be useful for decisions related to plantation, protection management, stock management and so on (2)*
Content	15	*An important parameter to have in historical, seasonal and long-term is total annual precipitation (2)*

users' feedback, which allowed for a more logical parameters' selection order. Interactivity also considerably increased by adding selectors and filters. In addition, screen guidance improved by including information pop-ups with short explanations of the available selection options and descriptions of the different bioclimatic indices and risk indicators (comment 7). Considerable effort was put into reducing the map loading time and establishing error prevention measures, such as the addition of a loading symbol to inform users about the platform's activity (comment 5). Moreover, the possibility to export maps and data in user familiar formats (e.g. CSV and image format) was implemented (comments 6 and 11).

Nevertheless, it was not possible to address certain requests made by users during the project's lifetime. These included, for instance, the implementation of the dashboard in Portuguese (comment 4). This aspect is consistent with the widespread awareness of the benefits of considering the vernacular language of users in climate services' provision (Miraz et al., 2016). Nevertheless, the MED-GOLD Dashboard is currently only available in English, as extending the provided variables and indices to other crops and regions was considered a more pressing improvement to apply for maximising the impact at the pilot phase of the tool. Likewise, other low priority comments (8, 12, 15) did not entrain any modifications since they were not raised in subsequent interactions with new users. Another aspect mentioned by users was the possibility to see the actual range of 'normal' conditions for a particular variable or indicator in the past together with the provided categories: above-normal, normal, and below-normal (comment 13). This required some adjustments that could not be implemented during the project, but that can certainly receive further attention in future improvements and releases of the Dashboard.

Co-evaluation of the climate service for the wine sector

To assess the added value and acceptance of the MED-GOLD Dashboard for the SOGRAPE wine user as well as the broader wine sector, additional online workshops were organised by social scientists involved in the project. One of the workshops, addressed to SOGRAPE users, was run in April 2021 and counted with a total of 19 participants from different areas of the company (senior management, oenology, viticulture, R&D, production and logistics), 6 of whom had previously joined the co-development workshop. Moreover, 3 multi-language participatory workshops (in English, Portuguese, and Italian) were organised between December 2021 - February 2022, aimed at participants external to the project, working in the grape and wine sector, and who were already using climate information to support their activities. Participants in the different workshops were asked to provide examples of key decisions in their area of expertise that can benefit from knowledge about climate conditions throughout the year. In the external workshops, the conditions required to upscale and use the tool in organisations beyond those involved in the project were also explored.

Participants' answers confirmed that using climate information in the time scales available on the Dashboard could provide benefits to the medium-term planning of the wine sector, mainly for decisions regarding the improvement of stock management and the effective scheduling of seasonal labour. The identification of potential locations for planting or purchasing vineyards was identified as the main benefit in the long-term (Khosravi et al., in this issue). Moreover, one of the participating wine organisations with international presence encouraged the project to transform the MED-GOLD Dashboard, currently only providing data for the Iberian Peninsula, into a publicly accessible tool, upscaling it to allow wine regions around the globe to make climate-smart decisions.

Adding to these qualitative assessments of the potential added value provided by the MED-GOLD Dashboard, a quantitative analysis was conducted to explore the optimal use of climate forecasts, considering the costs and benefits incurred by the SOGRAPE wine company (Vigo et al., in this issue). This work focuses on the application of seasonal forecasts of the Spring rain index (available on the Dashboard) in vineyard risk management. As a result, the study proposes a methodology that allows wine sector users to identify the optimal probability threshold triggering a particular decision based on seasonal forecasts.

Lessons learned and conclusions

Co-production of knowledge is an effective way to produce usable climate science results through a process of collaboration between climate scientists and decision makers, which are more likely to be accepted and used (Meadow et al., 2015).

This study describes the modes of engagement and collaborative research used for the co-production of a climate service aimed at the wine sector in the context of the European project MED-GOLD. During the co-production process, the repeated interaction between scientists and wine sector users allowed partners to frame the research questions together, decide how to answer them, and test the results. The phase of knowledge exchange called for an initial identification of the users' needs, followed by the exercise of matching the users' expectations with what scientists were able to deliver, and continued with a joint definition of how climate services for the wine sector should look like. The process continued with the stage of co-development of the climate service, where the recurrent collection and implementation of the feedback provided by users allowed optimising the usability of the wine pilot service. Then, the co-evaluation of the service was performed to assess its overall usability and acceptance among the project user and other stakeholders. Indeed, only a service that proves useful and practical for users, and that is tested with them, can have a role in decision-making processes, meaningfully informing decisions that require consideration of past, current or future climate changes (Bojovic et al., 2021).

The need for demand-driven climate information involves avoiding prior assumptions on the stakeholders' expectations. With this aim, an agile methodology was implemented throughout the co-production process, which allowed us to adjust the project developments as scientific outcomes and users' needs evolved. An example of that is the co-development of the MED-GOLD Dashboard, which was initially not planned but that emerged as desirable after identifying the need for a tool with a visualisation component. This shows that often climate science produces outputs that are difficult to use, either because they may be incompatible with the decision at hand or non-scientists may lack the technical capacity to interpret and use them (Dilling and Lemos, 2011; Findlater et al., 2021; Terrado et al. 2019), signalling these outputs should be better tailored to users' capabilities. Furthermore, despite being initially conceived to deliver climate information only to the grape and wine sector, the Dashboard was also proven to be useful for other sectors, such as the olive and olive oil, durum wheat and coffee, with additional indicators added in later releases to address the needs of such sectors.

Another lesson learned in the co-production process was the importance of having 'champion users' who co-develop the service, ensuring that it can truly inform their decision-making needs, and pioneering its use (Bojovic et al., 2021). In MED-GOLD, the 'champion user' SOGRAPE acted as an ambassador for the wine sector, promoting a broader uptake of the climate service and contributing to a new cycle of engagement activities (Fig. 1). The user also contributed to raising awareness of the climate service among different European and international organisations connected to wine sector activities. This shows that other stakeholders not involved in the co-production process may consider using or be willing to recommend the tool.

There are also some limitations that arise from the co-production of climate services tools with a single user, such as the potential difficulties for upscaling (Lu et al. 2022). Therefore, further research is needed to understand how the knowledge coproduced with SOGRAPE can be scaled up to users with other profiles and requirements. On this point, the development of methodologies that allow to assess the socio-economic benefits of decisions based on the use of climate services, can promote the uptake of climate predictions in agriculture (Vigo et al. in this issue). Finally, with the MED-GOLD Dashboard, the project has made a big effort to respond to users' demands for continuous and consistent climate information, regardless of the different data sources from which it is generated (e.g. encompassing different temporal and geographical scales). In this regard, the implementation of seamless approaches in climate services is another active field of research that can enhance future climate adaptation in the agriculture sector (Ruti et al., 2020).

Overall, this work has set the basis for a successful collaborative mode of engagement and research in the co-production of climate services for the wine sector. This foothold, established in the framework of the MED-GOLD project, can serve as useful guidance in the standardisation of future climate services' components to better support sectoral risk management in the agriculture field and beyond.

CRediT authorship contribution statement

Marta Terrado: Conceptualization, Methodology, Writing – original draft. **Raül Marcos:** Conceptualization, Investigation, Writing – review & editing. **Nube González-Reviriego:** Conceptualization, Investigation, Writing – review & editing. **Ilaria Vigo:** Writing – review & editing. **Andria Nicodemou:** Writing – review & editing. **Antonio Graça:** Conceptualization, Investigation, Writing – review & editing. **Marta Teixeira:** Writing – review & editing. **Natacha Fontes:** Investigation, Writing – review & editing. **Sara Silva:** Writing – review & editing. **Alessandro Dell'Aquila:** Project administration, Writing – review & editing. **Luigi Ponti:** Project administration. **Sandro Calmanti:** Project administration. **Marta Bruno Soares:** Methodology, Investigation. **Mehri Khosravi:** Methodology, Investigation. **Federico Caboni:** Software, Data curation.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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Appendix A. Supplementary data

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