Climate Services 30 (2023) 100346

Contents lists available at ScienceDirect

Climate Services

journal homepage: www.elsevier.com/locate/cliser

Monitoring climate related risk and opportunities for the wine sector: The MED-GOLD pilot service

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A B S T R A C T

MED-GOLD was a 54-months research and innovation project, whose main aim was to co-develop climate services for three staples of the Mediterranean food system, namely grapes, olives and durum wheat. This paper describes the methodology adopted for the co-development of the pilot climate service for the wine sector, focusing on the Douro Wine Region in northern Portugal.

In the first step, the MED-GOLD industrial partner SOGRAPE identified key decisions and users' needs for the wine sector in the Douro region by involving managers from their own vineyards in that region. From this information, the relevant bioclimatic indicators (and associated essential climate variables) were selected. Afterwards, two compound risk indices, the Sanitary and Heat Risk indices, were introduced as a combination of some of the aforementioned bioclimatic indicators. This methodological work was validated against the empirical climate characterization for the region of interest, of several 'bad' and 'good' years chosen by users according to their recollections of grape and wine production outcomes, namely quality and yields. In this paper, the overall strategy for selection of these years is presented. The components of the service based on historical climate, seasonal predictions and longer-term climate projections are described along with the visual interface developed: the MED-GOLD Dashboard, an interactive tool that displays detailed historical climate data, seasonal predictions and climate projections. The Dashboard consists of an ICT platform with a map-based user-focused front end to aid easy access to and manipulation of the data. The Dashboard was iteratively co-designed with the users to ensure their needs were met.

Practical Implications

In the framework of the H2020 project MED-GOLD, a pilot climate service for the wine sector has been co-designed with the industrial partner SOGRAPE Vinhos and implemented at prototypal level. Being the largest wine company of Portugal producing wines from vineyards managed in seven Portuguese wine regions and in an additional four countries across the world, a family-owned company with long-term vision, sustainability and intergenerational concerns, SOGRAPE needs climate predictions informing vineyard, winery and wine market strategic planning and operational management, at adequate temporal and spatial scales in formats providing fast and easy understanding, interpretation and action by its technical staff.

Grape and wine production is strongly dependent on weather and climate, and is therefore highly affected by climate change. Climate change is expected to accelerate and probably disrupt phenological processes of the grapevine. Indeed, projections on grape maturity and harvest data reported expected growth-cycle advances and/or shortenings over an increasing number of several years for many varieties across different winegrowing regions.

The co-development of a climate service for the wine sector is a

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https://doi.org/10.1016/j.cliser.2023.100346
Received 7 March 2022; Received in revised form 27 June 2022; Accepted 24 January 2023

multidisciplinary effort encompassing industry and policy decision makers, scientific and technical partners. Consequently, the methodology adopted should be varied and tailored to each feature and time-scale. All the methodological steps taken in the overall implementation of an effective service should follow either a co-design approach or a fluid communication scheme to involve the industrial user at all stages of the tool's development.

The methods used for the MED-GOLD Pilot service for the wine sector are framed within a specific area (i.e. the Douro region), however the workflows developed make use of datasets with global coverage tailored to a specific area through regional and local data. The Douro region was chosen because of its size and economic importance, its particular location and rugged geomorphology, which makes useful climate predictions hard to produce. Additionally, a general strategy has been adopted to transform a qualitative narrative on the specific risks for the grape and the wine production in the Douro area, based on the 75-year field experience of SOGRAPE (who manages 11 vineyards in the Douro Valley totalling over 600 ha), into compound indices that provide a quantitative measure of risk for relevant events of impact for the wine business. This user-driven approach could help the replicability of the work done to other areas and sectors and crops.

The MED-GOLD Wine service could be summarised in a number of steps:

1) Identification of the key decision and users' needs in the workshops held in the early stages of the project
2) Identification of Essential Climate Variables (ECVs) and bioclimatic indicators of interest based on the main outcomes of step #1
3) Identification of recent 'good' and 'bad' years for the wine sector in the Douro region, based on the field experience of SOGRAPE.
4) Construction of two compound risk indices that could provide a quantitative measure of specific risks for the wine business based on field experience.
5) The visual interface: the MED-GOLD Dashboard has been implemented as the visual interface of the front-end and back-end of the wine pilot service interactive tool. From meetings and workshops conducted with diverse users from the wine sector (professionals, regulators, researchers) insights were obtained that led to report the MED-GOLD Dashboard information in three different times scales; historical weather observations, seasonal forecasts and long-term climate projections
   a) Reconstruction of past and present climate over the areas of interest for the MED-GOLD wine service: the assembled collection of ECVs, bioclimatic indicators and ad-hoc developed compound risk indices have been used to reconstruct the past and present climate over the areas of interest of the service. This provides users with an exhaustive overview of the quality of observational climate datasets in reproducing the main features (crop growth and stresses, yields and quality) for the wine sector over the areas of interest.
   b) The historical seasonal forecasts of the aforementioned three 'layers' (i.e., the ECVs, the bioclimatic indicators and the risk indices) were evaluated over the entire Iberian Peninsula and the domain of interest for the MED-GOLD wine-sector. In addition, their 'real-time' forecasts for the growing seasons in the years 2020 and 2021 were provided. The analysis of the past and real-time seasonal predictions can give not only the performance of the predicted variables but also the predictions of the dedicated indicators/indices and their predictive skills to the wine users.
   c) Climate projections over the areas of interest for the MED-GOLD wine service: the projected changes in ECVs and relevant bioclimatic indicators are presented using a sub-ensemble of five bias-adjusted Regional Climate Models from the EURO-CORDEX modelling experiment specific for the Douro valley region of Portugal

This methodological workflow assures users that key climate-related information made available by the MED-GOLD wine service are in an easy-to-use manner for the decision making process of industrial users. The information at different time scales has a robust and well established scientific background, is authoritative, up- to -date and easy to be further improved in the future.

Data availability

Data will be made available on request.

Introduction

In this paper, the methodology adopted for the co-development of a pilot climate service for the wine sector in the framework of H2020 MED-GOLD project will be described.

MED-GOLD is a 54 months project funded by the Horizon 2020 programme within the European Union's Framework Programme for Research and Innovation aimed at developing a proof-of-concept agricultural climate service which focuses on three staples of the Mediterranean food system: grapes, olives, and durum wheat. The founding idea of MED-GOLD was to co-design and co-develop climate service prototypes with contributions from industrial partners in the wine, olive oil and pasta sectors (SOGRAPE, DCOOP, and Barilla, respectively) who participated in the consortium as problem-holders, being dubbed in the jargon of the project, the MED-GOLD sectoral «champions».

Regarding the wine sector, the European Union (EU) represents 45 % (3 362 000 ha) of the global vineyard area, 63 % (27.4 bn l) of global wine production, 57 % (24 billion l) of global wine consumption and 70 % (28.3 bn €) of the global wine trade. It is the most important continent in the world for the grape and wine sector and its Mediterranean area is the historical cradle of winemaking and wine trade (CEEV, 2015). The European wine sector is the Union's biggest agricultural exporter. With annual exports amounting to €11.5 billion in 2018, the EU Wine industry contributed a surplus of €8.9 billion to the EU trade balance. Portugal, despite ranking 13th member state in area and 11th in population (EUROSTAT, 2011) is the 5th largest wine producer in the Union, the only member-state to have 100 % of its territory under, at least, one geographical indication for wine and the first country in the world to have created an official wine appellation (Port in 1756). It is the member state with highest wine consumption *per capita* (OIV, 2021) while ranking as the 22nd (among 28) in terms of deaths caused by mental and behavioural disorders due to use of alcohol, all ages and genders confounded (EUROSTAT, 2018).

In Portugal, the wine sector plays an important role in economic growth and stability (Fraga et al. 2014a). Recent studies of Portuguese wine-growing areas (Fraga et al., 2014a) reveal fragility throughout the whole country and wine regions. In fact, climatic characteristics provide different wine growing potential for each region. Diverse geomorphology, traditional production practices and numerous native wine grape varieties (343 different grapevine varieties are authorised in Portugal for wine production - Ordinance no. 380/2012), contributed in the past to inter-annual oscillation in the quantity and value of wine produced.

The effect of climate change on grape phenology has been the subject of many studies (Jones and Alves, 2012, Koufos et al., 2014, Fraga et al., 2014b, Fraga et al., 2015). Global climate change will necessarily affect local climate impacts, namely grape phenology, grape quality and yield, both very dependent on annual climate at local scales. Grape maturity and harvest dates have advanced by 0.5–3.1 days per year in Australia for Cabernet Sauvignon, Chardonnay and Shiraz, and by 19 days in the

Veneto region of Italy during the period 1964–2009 for numerous varieties. Other locations in Europe have shown similar trends (Koufos et al. 2014).

Additionally, there is an increasing awareness of the importance of studying extreme events due to their impact on agriculture. Some studies report significant changes in the periodicity of extreme events, such as increased periods of drought in both the cold and warm seasons. Several studies (Ramos and Martínez-Casasnovas, 2006, Ramos et al., 2008) showed decreasing trends for occurrence of precipitation in the Mediterranean region. Other studies, at the vineyard scale, have shown high variability of environmental measurements observed within vineyards (Nicholas et al., 2011, Jones et al., 2005).

The vineyards of Douro Wine Region (DWR), located in a mountainous area in north-eastern Portugal, have complex geomorphology, creating multiple *meso*- and micro-climates. The region extends over a length of 100 km along the Douro valley, being mostly characterised by narrow valleys and steep slopes. The DWR covers an area of 2430 km^2 framed in the following geographic coordinates, N = 41.55, S = 40.92, W = −7.92, E = −6.75. Vineyards are planted up to 700 m in altitude, but because of climatic conditions conditioning the quality of grapes, the best wines have traditionally been obtained at lower altitudes where, usually, solar incidence and temperature are highest in summer (Magalhães, 2015).

Every vineyard in DWR is granted an annual Port production allowance according to a scoring method considering climatic parameters, among others, that rank them (A - best potential to F - least potential). This score not only affects grape value but also the value of the real estate (IVDP https://www.ivdp.pt/en/viticulture/vine-culture/).

In the MED-GOLD Consortium the role of Industrial «champion» for the wine sector has been played by the Portuguese company SOGRAPE. Possessing a global footprint both in terms of wine production and distribution, SOGRAPE is a family-owned company with a strong focus on sustainability and self-imposed targets to contribute for the UN Sustainable Development Goals. Identifying climate change as a serious threat to its business continuity as early as 2012, Sogrape has been continuously investing in acquiring climate knowledge, capacities and mitigation allowing for making climate-informed management decisions.

Starting from these preliminary considerations, in the framework of MED-GOLD project a pilot climate service has been co-designed and implemented following the steps described in the next sections.

Data

Ipma

The Instituto Português do Mar e da Atmosfera (IPMA) operate a network of automatic weather stations across Portugal, with 78 located in the mainland, which results in an average of 1 station per 1000 km2. This network gives real-time weather data needed for production of forecasts and monitoring of climatological processes.

Pthres

PTHRES is a high-resolution gridded observational dataset containing daily temperatures (maximum, mean and minimum) for Portugal from 1951 to 2015 with approximately 1 km horizontal resolution (Fonseca and Santos, 2018). The data were derived from the 25-km resolution E-OBS dataset (Cornes et al., 2018). Data from PTHRES have been validated with observations from 23 Portuguese weather stations that were not included in E-OBS to establish the dataset reliability for historical climate values on the locations where Sogrape provided crop data. The PTHRES dataset was provided to MED-GOLD partners by the University of Trás-os-Montes and Alto Douro (UTAD).

Era5

ERA5 is the latest climate global reanalysis produced by the European Centre for Medium-Range Weather Forecasts (ECMWF), providing hourly data on many atmospheric, land-surface and oceanic climate variables for the period from 1979 to the present. For more information on this reanalysis see Hersbach et al. (2020). The indices obtained from ERA5 data for the MED-GOLD wine service are freely available (Dell'Aquila et al., 2021).

SEAS5 seasonal forecast

The ECMWF SEAS5 is the fifth generation of global seasonal prediction. It replaced the former System 4 and uses the Integrated Forecast System (IFS) Cycle 43r1. There are 25 ensemble members for the hindcast period from 1993 to 2016. SEAS5 includes enhancements in the land-surface initialization, atmospheric resolution and the ocean model when compared to the previous System (Johnson et al., 2019). Climate data produced by the seasonal predictions were obtained from the Climate Data Store of the Copernicus Climate Change Service (CDS-C3S).

EURO-CORDEX climate projections

The climate projection work employs daily maximum, minimum and mean temperatures, as well as daily precipitation for the Douro valley from a five member GCM-RCM sub-ensemble simulations (Table 1, Bartók et al.,2019) from the (EURO-CORDEX) modelling experiment (Jacob et al., 2014). The spatial resolution of the models is 0.11° (~12 km) covering the European domain for three periods: 1971–2000 which is used as the reference period (or "baseline"), and the periods 2031–2060 and 2071–2100 under two Representative Concentration Pathways (RCP) scenarios, RCP4.5 and RCP8.5, which assume moderate and high emissions of greenhouse gases respectively.

Non-climate data

The non-climate datasets on the numbers of spraying treatments, wine production and grape quality are from SOGRAPE records and recollections and also official DWR sources such as institutions of the Ministry of Agriculture: Regional Direction for Agriculture and Fisheries - North (DRAP-N) and Institute for Port and Douro Wines (IVDP).

Sanitary warnings database: climatic conditions drive the emergence of diseases in the vineyard, for which prolonged humidity, due to continuous precipitation, is favourable. In the fight against those diseases, it's necessary to apply plant protection products to limit their spread and reduce the impact on the vineyard. One measure to account for the pressure of climatic conditions over vineyards for a given year is the number of sprayings that were recommended by advisory services and the extent of the period they covered during that year.

Yields database: the regional production of wine is an adequate measure of annual regional yield and also provides a window into the historical influence of climate over this factor of economic importance.

Grape quality database: climate directly influences the accumulation of sugars in the berry, which, in turn, will potentially be converted into alcohol, as well as boosting other sensory-active compounds. Through

Table 1
List of regional climate models used.

Institute	RCM	GCM
SMHI	RCA4	HadGEM2-ES
SMHI	RCA4	CNRM-CERFACS-CNRM-CM5
IPSL-INERIS	WRF331F	IPSL-IPSL-CM5A-MR
KNMI	RACMO22E	ICHEC-EC-EARTH
MPI-CSC	REMO2009	MPI-M−MPI−ESM−LR

the chemical analysis of these compounds in grapes just before harvest, it is possible to establish an association with the climate to which the berry was subjected during maturation.

Identification of users' needs and key decisions

To understand and assess the needs of users within SOGRAPE and the type of decisions that could be enhanced by the climate service, four focus group discussions were pursued in 2018. The four focus groups were integrated by a complete representation of the company's decision chain in productive and procurement operations in Portugal, including vineyard and enology managers, directors and C-level executives. MED-GOLD partners were able to engage with process managers from SOGRAPE who oversee key operations in the Douro Wine Region and better understand the importance of information and knowledge of future weather conditions in their decision-making processes. Because Sogrape farms over 600 ha of vineyards and acquires grapes from more than 1000 farmers in that region, the focus groups provided diverse, comprehensive and useful insights into SOGRAPE's operations. From these focus groups discussions, it became clear that having access to such services with an acceptable level of reliability from the predictions would be important and allow the users to consider applying that knowledge in decision-making processes, improving the company's sustainability performance.

The key decisions highlighted by users included:

- Choice of region and site for establishment of new vineyards,
- Choices of grape varieties for planting,
- Choice of grapevine rootstock and clone for planting,
- Planning and management of cropping operations,
- Management of agricultural machinery according to operational planning,
- Maturation control planning,
- Setting of harvest dates,
- Stock Management (products and consumables for viticulture and winemaking)

From this interaction, it was also possible to ascertain the expectations and establish a user-driven ambition for minimum thresholds of requirements that would enable them to trust the service provided. The requirements varied depending on the level of impact certain decisions can have on the company costs.

It was thus possible to establish that, for seasonal forecasts, SOGRAPE users ideally wished for 6-month lead-time weekly forecasts of temperature and precipitation, to be updated weekly, and with a minimum accuracy of 70 %, i.e. that the forecasts would match the observations 70 % of the time. A few participants also highlighted their preference to receive this information in a format easy to interpret, understand and use. For long-term climate projections, users requested projections of average temperatures (maximum and minimum) and precipitation totals ideally with quarterly updates. Additionally, it would be important to quantify the expected magnitude of increase or decrease in temperature. The original ambition of the users on the agreed minimum reliability for which they would consider using such projections in strategic decision-making would be 80 %.

Identification of bioclimatic indicators relevant for the wine sector

Five bioclimatic indicators (and associated ECVs) related to vine growth, grape yields and harvest dates have been identified by SOGRAPE (Fontes et al., 2016) and were introduced in the early stages of the project (see Bruno Soares et al 2019 and references therein). These indicators are: spring total precipitation (SprR), harvest total precipitation (HarvestR), growing season temperature (GST), warm spell duration index (WSDI) and the number of heat stress days (SU35). The definitions of these indicators together with their viticultural meanings are summarised in the following paragraphs.

Spring total precipitation (SprR)

SprR is the total precipitation from 21st April to 21st June (for the Northern Hemisphere). The wetness of spring represented by this indicator will affect the level of vigour which is associated with fungal disease risk and, in turn, affects the number (and associated costs) of protective treatments and vineyard operations.

Dry springs will delay vegetative growth and reduce vigour (i.e. speed of growth of the grapevine canopy, Rives, 2000). And leaf area total surface. Moreover, fungal disease pressure will be lower and therefore there will be less need for protective and/or curative treatments, which translate into lower costs. Wet springs will promote greater vigour, increase the risk of fungal disease and disrupt vineyard operations, as they may prevent machinery from entering in the vineyard due to mud (usually associated with higher costs).

Harvest total precipitation (HarvestR)

HarvestR is the total precipitation from 21st August to 21st October (the usual harvest period in the Northern Hemisphere). Winegrowers and winemakers experience the major risks during the harvest season. Precipitation during this period influences the quality and quantity of berries through physiological processes.

Wet harvests are one of the major risks for both winegrowers and winemakers. Light and moderate rainfall during the summer can be positive, especially in arid areas, as it provides the necessary water and humidity for the physiological processes of the grapevine to occur, thus avoiding the need for irrigation. However, heavy downpours are detrimental to quality as berries will absorb water and dilute quality compounds. Yields may be further reduced if heavy rain is accompanied by hailstones. Continuous rainfall during the harvesting period sets the conditions for widespread fungal infections destroying berries, causing grapes to develop acetic acid bacteria and increasing levels of acetic, gluconic acids, ethyl acetate and other compounds that are detrimental to wine quality. Additionally, in areas with deep soils, rain during harvest hampers mobility, hindering the movement of machines and people. This generally leads to speed up the harvest activities before the quality of the grapes is totally lost. Therefore, ideally, the harvest period should be wholly dry.

Growing season temperature (GST)

GST is the average of daily mean temperatures between 1st April and 31st October (for the Northern Hemisphere). The optimum range of GST varies with the grapevine variety, thus there are two ways of using GST: (i) to select the varieties for a given location or (ii) to determine the location for a given variety.

GST provides information on which varieties are best suited for a given site/climate or inversely, which are the best places to grow a specific variety. In a climate change scenario, it becomes an important indicator in terms of making decisions about planting or replanting a vineyard. For existing vineyards, GST also provides information on the suitability of its varieties for the climate of specific years, explaining quality and production variation. This indicator became more useful as climate change became observable in changing phenology and variety agronomic and enological performance, as a clear and intuitive way to have a general idea of which areas would gain or lose suitability to produce quality wines. Many grapevine varieties across the world have been ranked according to their optimum GST. This indicator can also be used to characterise the climate impact on grape and wine quality across different years as it impacts the growth cycle and phenology.

Number of heat stress days (SU35)

In MED-GOLD, SU35 was defined as the accumulated days on which the daily temperature maximum exceeds 35 °C between 1st April and 31st October (for the Northern Hemisphere). Above this threshold, the plant closes its stomata and stops photosynthesizing. If this situation occurs after veraison, maturation will be arrested until the situation releases. Thus, this indicator is associated with the level of sugar, polyphenol and aroma precursor concentrations in berries, all essential for grape and wine quality. Deprived from its normal energy source, the plant will turn to use organic acids that will decrease the acidity levels of the berry, decreasing its quality. The higher the indicator, the lower the quality potential of the berry and its aptitude to produce quality wine. The loss of acidity will mean, even for lower index levels, higher costs of correcting acidity (to balance wine taste and keep microbiological safety in musts) and water needs (to support grapevine's integrity in the face of high temperatures). There are inter- and intra-varietal tolerance variations in grapevines towards this threshold, 35 °C being an average threshold when photosynthesis stops and stomata close to protect itself from severe dehydration.

Warm spell duration Index (WSDI)

In MED-GOLD, the WSDI is defined as the 7-month count of days on which the daily maximum temperature exceeds the temperature corresponding to its 90th percentile for at least 6 consecutive days between 1st April and 31st October (for the Northern Hemisphere). It signals an extreme heatwave in a warm region and in turn increases additional losses due to flowering disruption (when too early in the season) and/or the dehydration of berry and leaf (e.g., berry skin sunburn, leaf and shoot desiccation and senescence) in addition to excessive water depletion.

Identification of 'Good' and 'Bad' years for the wine sector in the Douro region

In order to obtain an indication on how the selected bioclimatic indicators can provide a reliable overview of the behaviour of the productive season and the major features of interest of the grape-wine agrifood system in the Douro region, SOGRAPE has identified a number of 'good' and 'bad' years in recent decades, based on expert judgement, climate and non-climatic data already available (Sanderson et al., 2019). In general, the bad years were those when production was low, high sanitary pressure caused either crop or quality loss and/or incurred higher protection costs. The 'bad' years identified by SOGRAPE were 1988, 1993 and 2002. By opposition, 'good' years were years of fair production, high quality and moderate to low protection costs. The 'good' years identified by SOGRAPE were 2007 and 2011. The characterisation, generally below the target value, of these years in terms of sanitary risk, wine production and grape quality parameters is shown, respectively, in Figs. 1-3.

'Bad' Year 1988

Above average temperatures and higher than normal spring rainfall led to increased disease pressure (downy mildew - *Plasmopara viticola*), continuing well into the early summer (disease risk period from 19-Apr to 18-Jul, 90 days as reported in Fig. 1) which, because of an uncontrollable outbreak caused major yield losses, making this one of the lowest yielding years in recent decades (76×10^6 l against an average of 118×10^6 l in the previous 10 years and 162×10^6 l in the previous year, see Fig. 2). Favourable conditions during late summer and the harvest period were not enough to improve compositional and sanitary quality of grapes for wine production, which was also greatly affected by powdery mildew in many areas.

'Bad' Year 1993

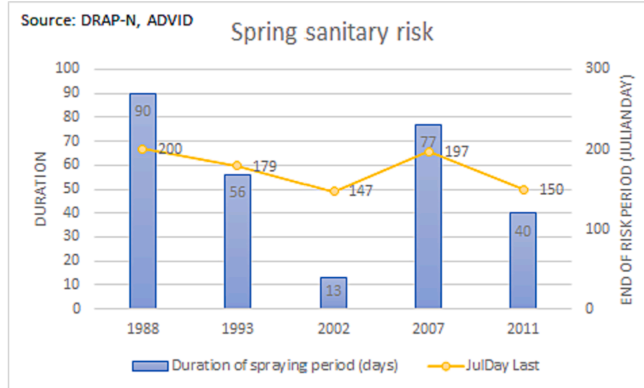

Fig. 1. Spring sanitary pressure indicators for DWR in chosen years (JulDay Last = last Julian calendar day of the spraying period). Duration of spraying period in bars is the interval in days between the first and last official warnings for fungal disease risk from State authorities. The line shows the date in Julian day of the issue of the last warning, i.e., the end of the risk period.

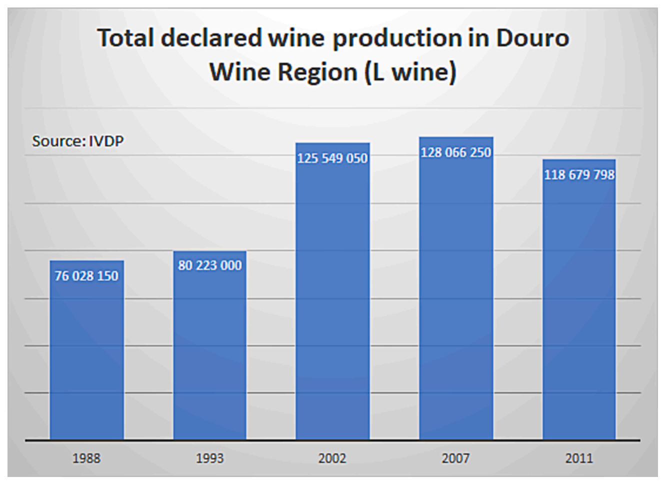

Fig. 2. Total DWR declared wine production in litres for chosen years. 1988 and 1993 are years with extremely low production in the considered dataset.

Dry winter conditions made for late bud-break. Temperature and precipitation levels were close to average, making for an average disease pressure, not too severe in early spring but worsening severely in the later part of the season (disease risk period from 3-May to 28-Jun, 56 days as reported in Fig. 1). Precipitation in late spring (April to June) was also very high. The warm summer temperatures anticipated a high-quality harvest until, in September and October, heavy and prolonged rains caused an outbreak of massive and widespread grey rot (*Botrytis, Aspergillus, Penicillium*, etc.), completely destroying the harvest quality and considerably reducing yields and wine value (Figs. 2-3).

'Bad' Year 2002

Late bud-break, due to some extreme episodes of low temperatures in winter and, especially to low winter and early spring precipitation, causing episodes of moderate to severe drought early in the season. Disease pressure was almost absent (disease risk period from 14-May to 27-May, 13 days, as shown in Fig. 1). However, vegetative growth was thus stunted, which meant harvests did not start until mid-September, and lasted well into October, when the equinoctial rains severely damaged grape quality (Fig. 3), diluting their contents and causing local outbreaks of rot (*Botrytis*) in some areas (Fig. 1).

'Good' Year 2007

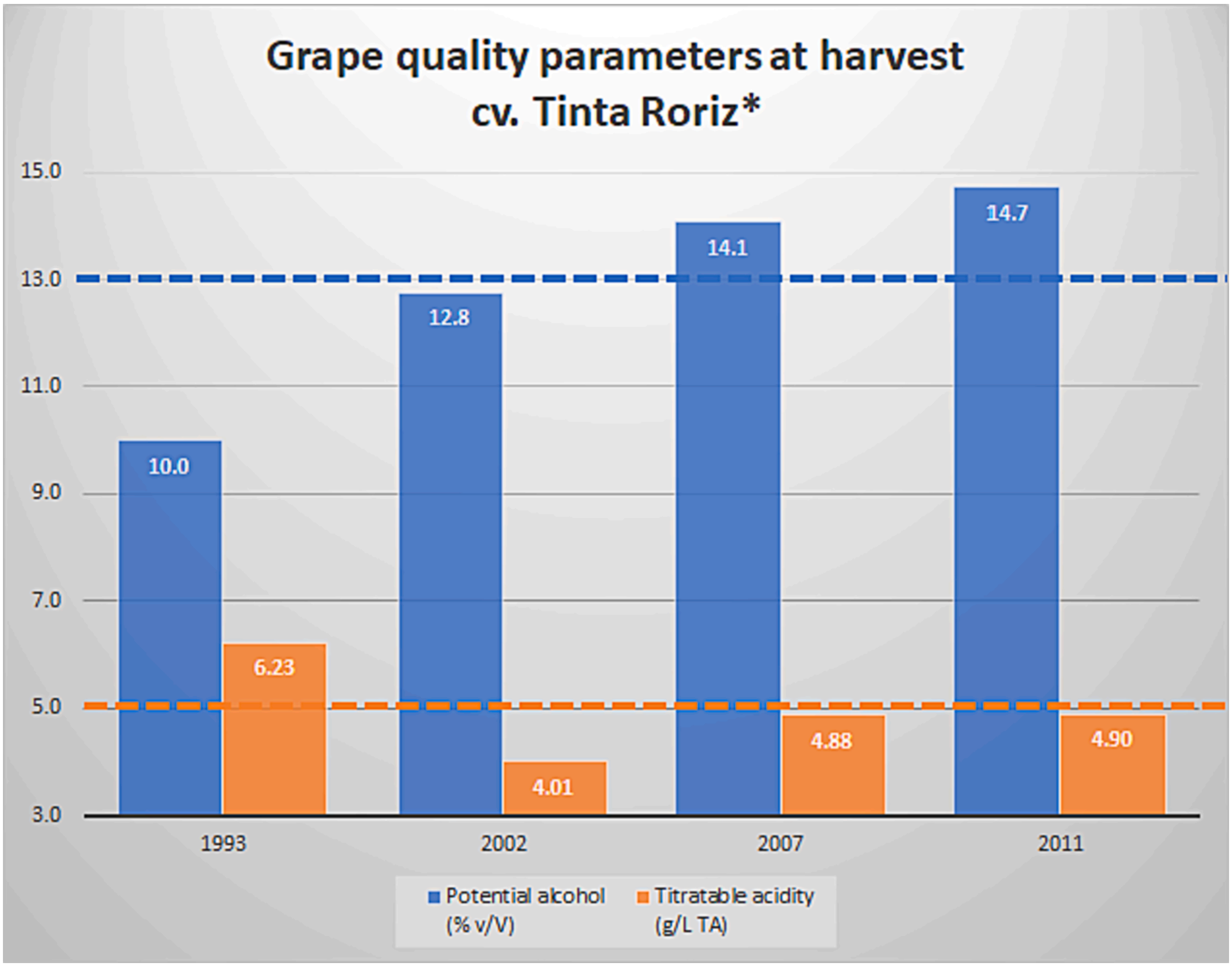

Fig. 3. Grape quality parameters for a DWR representative grape variety (Tinta Roriz) in chosen years as recorded in SOGRAPE vineyards (dashed lines indicate target desired values for quality wine production). 1988 is omitted because the grape quality dataset starts in 1991.

A winter with normal precipitation amounts made for good water reserves that lasted well until summer due to milder temperatures that were not far above normal values. Disease pressure was moderate to high, but still within control, as temperatures did not promote outbreaks (Fig. 1 reports a disease risk period from 30-Apr to 16-Jul, 77 days). Regular and moderate episodic rainfall events during late summer were not enough to cause disease outbreaks and helped to maintain a good hydric status in the grapevines, leading to extremely high quality grapes, especially in terms of aromatics and colour intensity. Harvest started in mid-September without major rain events, sustaining the high quality of the grapes (Fig. 3).

'Good' Year 2011

Mild temperatures throughout the growth cycle caused a relatively late bud-break and a smooth, regular vegetative growth with almost no disease pressure (disease risk period from 20-Apr to 30-May, 40 days see Fig. 1). The absence of the usual high temperature extremes during the maturation phase, together with small amounts of precipitation were

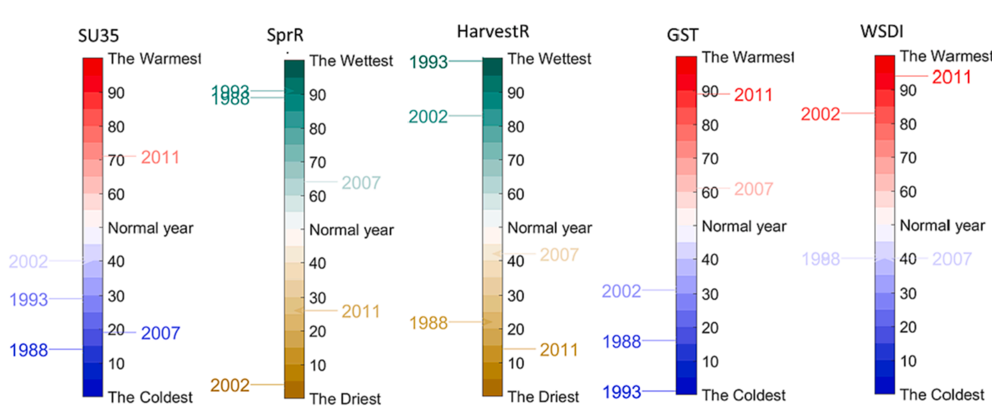

Fig. 4. Ranking of 'bad' (on the left side of each bar) and 'good' years (on the right side of each bar) in terms of percentiles of the selected bioclimatic indicators for the representative IPMA weather station of Santa Barbara, DWR.

not enough to cause disease pressure but sufficient to support the grapevine hydric status. These conditions led to the development of grapes that were very balanced and even with more concentration of secondary metabolites (anthocyanins, total phenols, organic acids, flavour precursors, etc.) than in 2007, which were harvested untouched and in pristine conditions, due to the general dry harvest conditions. Considered as perfect a year as one might get.

The characterization of 'good' and 'bad' years in terms of the selected bioclimatic indicators described above is reported as an example in Fig. 4 using data from the IPMA Weather station of Santa Barbara. This weather station (Lat = 41.173 N; Lon = 7.549 W) was chosen as a representative sample of IPMA weather stations with a long time series and very little data missing. It is also located close to one of the SOGRAPE vineyards in the DWR. All the chosen bioclimatic indicators are reported here in terms of percentile, ranked over a reference period 1979–2018. On the left side of each colorbar, the ranking of the 'bad' years is reported, while on the right side are reported the 'good' ones. Similar results (not reported here) have been obtained by considering the closest grid-point to the IPMA weather station from several gridded observational datasets (ERA5, E-OBSv19 and PTHRES).

The colour bars shown in Fig. 4 are quite consistent with the narrative description of the case years above reported. The SprR is also quite consistent with the sanitary periods represented in Fig. 1. The representation of 'good'/'bad' years in terms of percentiles of bioclimatic indicators was presented to SOGRAPE users (Bruno Soares et al., 2019).

- The 'bad' years 1988 and 1993 are characterised by a very high value of SprR and concomitantly low GST values (below the 30th percentile).
- 1993 exhibits the highest HarvestR of the entire period.
- 1993 is the only year since 1980 to show simultaneously extreme rainfall values both during Spring and at harvest time, which seems to be a rare coincidence (Sanderson et al., 2021)
- The 'good' years 2007 and 2011 show above-normal GST values (above the 60th percentile and near the 90th percentile, respectively), while all 'bad' years exhibit GST below-normal.

Co-development of the MED-GOLD compound wine risk indices

Looking at the results presented in Fig. 4, it is rather difficult to identify a 'good' or a 'bad' year considering only the ranking of a single bioclimatic indicator (with a partial exception for GST): for instance, two years with a completely opposite outcome for the wine sector in the DWR (namely 1988 and 2011) exhibit quite similar values for HarvestR. On the other hand, three 'bad' years are at the two opposite ends of the SprR ranking (1988 and 1993 around the 90th percentile, while 2002 is below the 10th percentile). The reason is that the final behaviour of a specific season is generally due to the concomitance of several factors that could increase the risk of, for instance, having a higher number of infections, or a quality/quantity loss due to heat stress.

To better take this into account, ENEA and SOGRAPE have co-designed and co-developed two new compound risk indices that can integrate the different sources of risk into a single measure, during the growing season, for two relevant events that may have a relevant impact for the wine company:

- Pressure of fungal disease in grapes (Sanitary Risk Index)
- Heat stress (Heat Risk Index)

These two new compound risk indices were developed using the ranking of the bioclimatic indicators above selected weights to resemble the high-level narrative description of 'good' and 'bad' years. The overall methodological strategy is to use some new ad-hoc implemented integrated indices (based on and in addition to existing bioclimatic indicators) that can give an idea of the main risk factors that can affect wine production (in terms of quality, quantity and derived inherent value) in the DWR. First, we had to test and tune the methodology on the past seasons, using observational datasets to assess whether this strategy can correctly reproduce what happened in the recent past from a wine production perspective (favourable or unfavourable conditions for obtaining value from wine production). Subsequently, we applied the same methodology to the output of available climate predictions (from seasonal and longer time scales). A similar approach has been recently adopted, even if in a quite different context, in Nyadzi et al., 2022.

MED-GOLD compound Sanitary Risk Index

The MED-GOLD compound Sanitary Risk Index integrates in a single measure the possible sources of fungal disease (downy mildew and rot) risk in the DWR during a growing season (this is linked to critical decisions to be made during the season, such as the number of sanitary treatments to be applied). From the above description of 'good'/'bad' years and the experience of SOGRAPE experts, possible sources of risk of infection by fungus have been identified:

1. High/Low SprR (with very high SprR, the overall sanitary risk is even higher; with high GST, the risk related to SprR is increased)
2. High HarvestR (especially in case of low GST)
3. Low GST

Starting from these considerations, a first version of a normalized compound Sanitary Risk Index was introduced based on the percentile values of GST, SprR, HarvestR, properly combined in order to adjust to the behaviour observed in the test-case years. The weights of the single coefficients and the rules reported below were finalised after several fine-tuning and double-checking iterations between ENEA and SOGRAPE:

$$Sanitary\ Risk\ Index = off_{gst} \times off_{sp} \times (percentile(SprR)) + off_{hart} \times percentile(HarvestR) + (100 - percentile(GST));$$

with: $off_{hart} = 1.$; $off_{sp} = 1$; $off_{gst} = 1.$;

➔ *if percentile (SprR)>= 60;* $off_{sp} = 1.5$;
➔ *if percentile (GST)<= 40;* $off_{hart} = 1.5$;
➔ *if percentile (GST)>=70;* $off_{gst} = 1.5$;

where off_{hart}, off_{sp}, off_{gst} are the coefficients for weighing the different sources of risk: harvest precipitation, spring precipitation and growing season temperature, respectively. For a season where the SprR exceeds the 60th percentile, then $off_{sp} = 1.5$: in such a way the weight of the risk associated with SprR is increased further by 50 %. The risk associated with SprR is also increased if the GST is very high (i.e. if GST is above the 70th percentile we'll put $off_{gst} = 1.5$). On the other hand, if the GST is below the 40th percentile, the grapes may ripen more slowly and the risk associated with high HarvestR is increased by setting $off_{hart} = 1.5$.

The index is then normalized to values between 1 and 100 over a common reference period, the same chosen for computing the percentile distribution of the bioclimatic indicators.

MED-GOLD compound Heat Risk Index

The MED-GOLD compound Heat Risk Index integrates the possible sources of heat stress risk in the DWR during a growing season into a single measure. From the above description of 'good'/'bad' years and the experience of SOGRAPE experts, possible sources of heat stress risk for grapes have been identified:

1. High GST
2. High SU35
3. High WSDI

A first hypothesis of a heat risk index based on the percentile values of GST, SU35 and WSDI includes the same weight for all three factors:

$$Heat\ Risk\ Index = percentile(GST) + percentile(SU35) + percentile(WSDI).$$

As for the Sanitary Risk Index, also the Heat Risk Index is then normalized to values between 1 and 100 over a common reference period (1979–2018).

A visual interface for the wine service: The MED-GOLD Dashboard

All the climate information presented in the above sections, for the different timescales of interest for the users (historical climate, seasonal forecast, long-term projections) and type of variables (essential climate variables, bioclimatic indicators and risk indicators) are reported in the MED-GOLD Dashboard.

The MED-GOLD Dashboard is an interactive web-based application designed to provide a visualisation tool for stakeholders, allowing them to browse and view, in a user-friendly way and without any programming knowledge or the need to manage climatic data files (typically in NetCDF or GRIB formats). In addition to information for the wine sector, information for the MED-GOLD pilot services for olive oil sector and an example for the durum wheat sector are also included (not shown here).

Users can interact with the Dashboard via a graphical user interface, subdivided in three different tabs, each of them containing information at different timescales (historical climate, seasonal forecast and long-term projections) and organised in a step-by-step process (see sections below for more details). The interface has been organised, starting from users' requirements collected in a number of virtual meetings, in a way that enhances navigation, taking into account the dependencies among the different fields as well as navigation aspects. Thus, the organisation of the information guides users through the selection of the relevant parameters: first the type of information (climate variable, bioclimatic indicator or risk index), then the region (Douro Valley, Iberian or Italian Peninsula), the particular variable of interest, the time period of interest, as well as other options and filters that can change according to the selected tab (e.g. apply mask of forecast skill, select the preferred GHG emission scenario, etc).The interface also provides the possibility to search a location on the map by geographic coordinates, city or country. The selected query is executed in real time on the MED-GOLD ICT (Information and Communication Technologies) platform, based on the cloud resources of AWS (Amazon Web Services), and its results are dynamically plotted on a geographical map, using mapbox as a backend service. Results of the query are visualised as heatmaps, which are graphical representations of data where values are depicted by colours. Specific colour palettes were chosen according to users' feedback. Clicking on the map opens a window with more detailed information about the selected grid point for users that want to explore additional information. This strategy allows users to consume information step-by-step and on-demand avoiding overwhelming effects.

Since the MED-GOLD Dashboard is meant to be a comprehensive environment for stakeholders, it also provides simple data export options, allowing users to easily retrieve the data visualised on screen allowing further off-line processing. Data can be exported (see Figs. 6, 7 and 9) as NetCDF (standard format for array-oriented scientific data). Plotted maps and charts (see Fig. 8) can be exported as image files (PNG or JPEG). Following users' feedback, a CSV export option was added during the development iteration, since many of the users indicated this is a format that can be easily opened with software they are familiar with (e.g. MS Excel).

The Dashboard REST (REpresentational State Transfer) API (Application Program Interface) allows automatic and remote access to all the data and query capabilities. The REST API is, in fact, the technological foundation upon which the Dashboard itself is built and relies, in turn, on the data pipeline implemented by the ICT platform, that takes care of data import, storage, processing and format conversions. The availability of a REST API that provides the same functionalities of the Dashboard application, enabling further machine-to-machine integrations between external systems and the MED-GOLD ICT platform, has been identified as an important point in users' feedback.

The diagram shown in Fig. 5 highlights the relationship between the Dashboard and the overall MED-GOLD ICT platform in a concise way.

A basic tutorial has been also produced in different languages (along with an explicative video. On the top right corner (Figs. 6,7,9) of the homepage there is a feedback form to contact the development team about enquiries on the use of the Dashboard, bugs, possible suggestions and comments on the design and functionalities of the application.

Historical climate component for the MED-GOLD wine service

As highlighted in the several interactions with the users, historical climate information of the MED-GOLD Wine service could definitely help them with better harvest planning and cost justification.

The 'Historical Climate' tab of the MED-GOLD Dashboard gives the user the opportunity to consult historical (up to the present) monthly data for essential variables, bioclimatic indices and wine risk indicators. The available options (Fig. 6) are:

1. **Timescale:**
   - Historical Climate: past and near-present information [Default and here selected].
   - Seasonal Forecast
   - Long-Term Projections
2. **Location** *(search by geographic coordinates, city or country)*.
3. **Type of variables:**
   - *Climate variables*: temperature & precipitation monthly data.
   - *Bioclimatic indicators:* indicators taking into account the climate and phenology of the vine, e.g. GST, SprR, HarvestR, SU35, and WSDI.
   - *Wine risk indices:* risk of diseases (Sanitary Risk) or heat damage (Heat Risk).
4. **Region**: region of interest (Douro, Iberian Peninsula or Italy).
5. **Variable of interest** *(hover over each variable for explanation)*.
6. **period of interest.**

   For the Douro Valley, PTHRES dataset is used, spanning 1951–2015, at 1 km of spatial resolution. For the Iberian Peninsula (and Italy as well for the durum wheat service), ERA5 dataset is used, spanning 1979–2020, at 31 km of spatial resolution (approximately).
7. **Filter:** Data for each single year or averaged over the period 1981–2010.
8. **Export data:** The maps can be exported in.csv (ascii format readable by spreadsheet applications like Microsoft Excel or OpenOffice), or. netcdf (standard for scientific computation., readable by basic Java application such as Panoply https://www.giss.nasa.gov/tools/panoply/, for example) or as images in.jpg format.

By clicking on the map (or by selecting a location in the above step #2), a chart will appear with the time series of the requested field (see Fig. 6). The time series can be printed or exported as a csv file or as an image in.jpg or.png format.

Seasonal forecast component for the MED-GOLD wine service

Seasonal predictions are a risk-mitigation asset that allows winemakers and farmers to adapt their decision making to the risks posed by near-term climate (e.g. using temperature and precipitation information from one to several months into the future). Given that operational seasonal predictions are issued by a number of forecast services including ECCC (Merryfield et al., 2013); UK MetOffice (Williams et al., 2018); NCEP (Saha et al., 2014); Meteo-France (Voldoire et al., 2019);

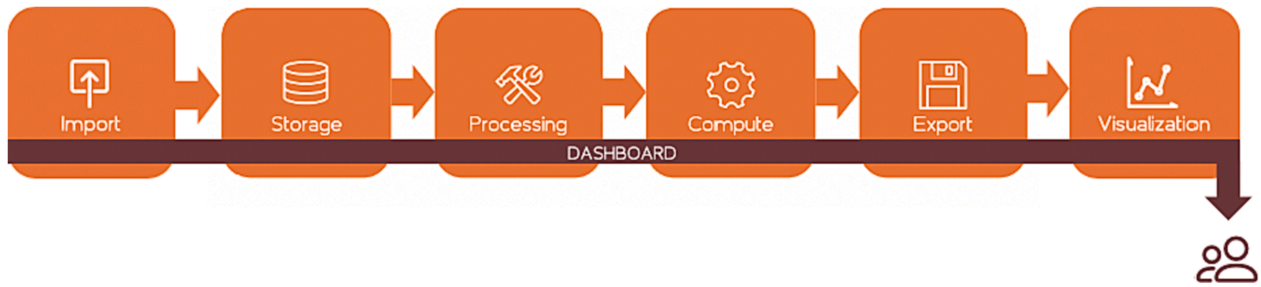

Fig. 5. As shown in the diagram below, MED-GOLD Dashboard (dark red path) utilises all sub-modules of the MED-GOLD ICT platform's data pipeline (in orange) in order to provide value to users. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

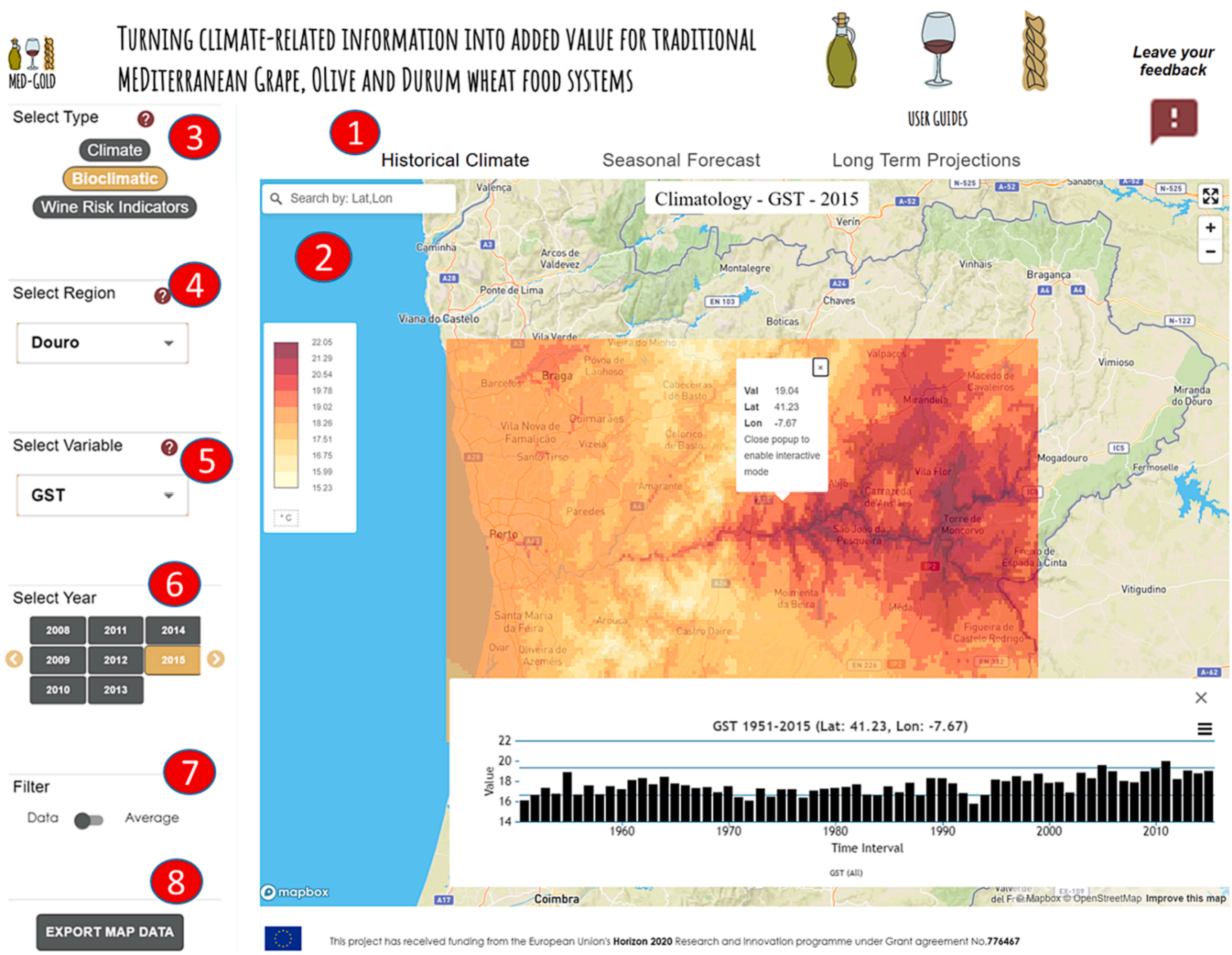

Fig. 6. Landing page for the Historical Climate tab: here is reported related the GST for 2015 (PTHRES data) with the observed time series for the grid point closest to Santa Barbara IPMA weather station.

ECMWF (a reliability study from Weisheimer and Palmer, 2014); JMA (Takaya et al., 2018); DWD (Stevens et al., 2013) and CMCC (Gualdi et al., 2020), the viticultural sector could also benefit from them (Buontempo et al., 2020). Hence, to try to increase the usability of these predictions, the MED-GOLD project provides tailored forecasts at three end-user levels of interest: essential climate variables (ECVs), bioclimatic indicators and compound risk indices.

However, even the state-of-the-art forecast systems produce climate estimates with systematic errors due to model imperfections, as well as other sources of uncertainty. Thus, the bias in predictions needs to be adjusted before the provision of the prediction to the end-user. In MED-GOLD, after testing different bias adjustment techniques, the Simple Bias Correction method (Leung et al., 1999; Torralba et al., 2017), which adjusts the seasonal predictions to have an equivalent standard deviation and mean to that of the reference dataset, was selected for implementing the seasonal pilot wine service workflow (see details in Chou et al., 2023). To match the resolutions of the predicted and observed ECVs, the ECMWF SEAS5 predictions were interpolated to the ERA5 grid before the calculation of the indicators and the following verification. Then, we progressively combined the observations and the predictions to increase the quality (skill) of prediction as the growing season progresses. Finally, after obtaining the indicators, the bias correction was applied to the indicators to remove the inherent errors of the climate model.

Assessment of the quality (skill) of seasonal predictions is achieved by comparing predictions of the past with an observational reference dataset (i.e. what actually happened) and deriving the Fair Ranked Probability Skill Score (FRPSS) measures from this comparison. In general, we say a prediction has skill (skill scores greater than zero) when the number of times the prediction matches the observation is higher than the number of times the historical average matches the same observation. In these cases, using the seasonal prediction for making decisions is better than using the historical average. Conversely, when skill scores are less than zero, the prediction does not have skill, which means it should not be used for decision-making. As such, users can easily visualise the quality of the seasonal predictions over the area of interest throughout the period from 1993 to 2021.

Instead of showing all the probabilities which can be made available to the users if needed, in the MED-GOLD wine service the ensemble seasonal prediction is portrayed in three categories or terciles: above normal, normal and below normal. These three baseline categories are obtained by looking at the past predictions (hindcast) and distributing them in three classes according to their magnitude and frequency (the middle class or normal, the above normal and below normal). Afterwards, the future prediction is assigned to one of these three categories following the most likely predicted category as long as the probability assigned to the most likely category is higher than 40 %. This approach has been followed taking into account the users' feedback, which prefer not showing probabilities at first glance in the visualisation to simplify the information for non-advanced users. Nevertheless, in future upgrades of the tool, the idea is to include an option that can be activated showing the probabilities corresponding to the categories for users interested in them.

The seasonal forecast tab of the MED-GOLD Dashboard includes the following elements:

1. **Timescale:**
   - Historical Climate
   - Seasonal Forecast: predictions for the next six months [here selected]
   - Long-Term Projections
2. **Location:**
3. **Type of variables:**
   - *Climate variables*: temperature & precipitation monthly data
   - *Bioclimatic indicators*: GST, SprR, HarvestR, SU35 WSDI
   - *Wine risk indices*: risk of diseases (Sanitary Risk) or heat damage (Heat Risk)
4. **Region**: Iberian Peninsula or Italy [only for the durum wheat MED-GOLD service].
5. **Variable of interest** (hover over each variable for explanation)
6. **Target period of the forecast**
7. **Forecast made in**: This starting date is the initial starting month of that specific forecast, i.e. when the forecast is issued.
8. **Filters**: Turn on the "Skill" filter option to hide areas where the prediction doesn't provide added value with respect to climatology (See Marcos-Matamoros et al., 2020 for major details)
9. **Export data:** The maps can be exported in.csv,.netcdf or as images in.jpg

The map reported in Fig. 7 is a Dominant Tercile Summary Map that shows, on a single chart, the areas where a specific tercile probability is prevailing (exceeding 40 %) over the others in the selected forecast. Such probabilities are computed by comparing the forecast probability density function (PDF) with the corresponding model climate PDF, estimated over the reference period (1993–2016). If the dominant tercile does not exceed 40 % that grid point is not assigned to any tercile

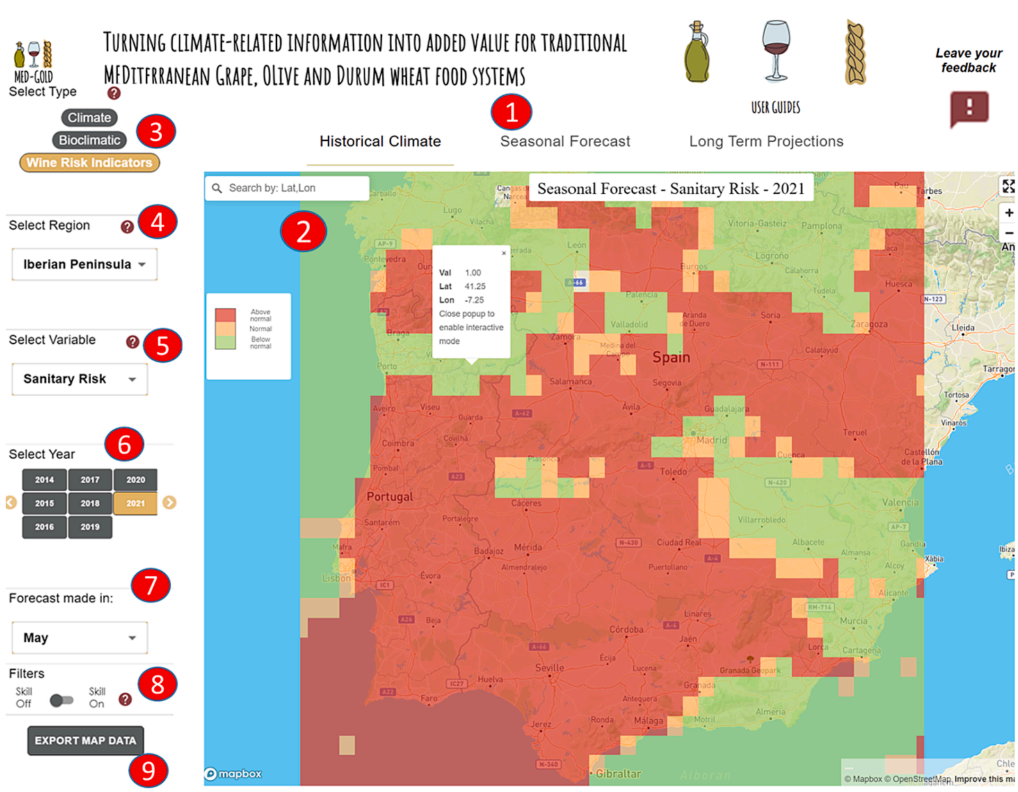

Fig. 7. Landing page for the Seasonal Forecast tab: here is reported the Dominant Tercile Summary Map for Sanitary Risk Index for the 2021 growing season from SEAS5 seasonal forecast issued in May 2021.

and it is not shown.

Also, by clicking on the map (or by selecting a location in the above step #2), a chart will appear with the time series of the observed / predicted categories for the requested field. For example, in Fig. 8 the Sanitary Risk Index for the grid point closest to the Santa Barbara weather station (*Sec*.5) has been reported. The colored squares report the predicted most likely tercile (above normal, normal and below normal) while the blue dots are the percentiles for the reference observational dataset (ERA5). The time series can be printed or exported as a. csv file or as an image. The main features of this picture have been agreed with the users: from this time series users can easily perform any kind of analysis on the performance of seasonal forecasts over a grid point of their interest (hit rate, accuracy…). Additional features, such as the probabilistic distribution of seasonal forecast for each grid point, are in principle obtainable and will be included, as an additional level of information, in the future operative release of the tool.

Climate projections component for the MED-GOLD wine service

As agreed from feedback from users at the workshop held in May 2019, the final component of the wine climate service is based on climate projections (Bruno Soares et al., 2019): projected changes in the future for ECVs and relevant bioclimatic indicators are presented.

The compound risk indices have not been computed over the climate projections because, from the interaction with users, it was highlighted that there was limited interest in these kinds of risk measurements over the longer-term (as reported in Bruno Soares et al., 2019). The compound risk indices have been developed measuring the risk observed in the present climate: in this perspective, their application to long term projections could be potentially misleading.

In the climate projections component, monthly data for temperatures (maximum, minimum and mean) and precipitation from a sub-set of five RCMs from the EURO-CORDEX experiment are utilised (*Sec*. 2.5).The data cover three periods: 1971–2000,used as the reference period, and the periods 2031–2060 and 2071–2100 under two Representative Concentration Pathways (RCP) scenarios, RCP4.5 and RCP8.5. The native horizontal resolution of the models is about 12 km and a two step process was followed in order to statistically downscale the climate projections to a resolution of 1kmx1km using the PTHRES gridded dataset (1 km x1km daily gridded dataset for temperatures and precipitation for Portugal as the reference dataset. In particular the daily climate projections for the variables used in the analysis were regridded to the PTHRES grid by means of bilinear interpolation, while in a second step bias correction is applied using the empirical quantile mapping (EQM). Regarding the bias correction method, EQM works by adjusting the 1–99 percentiles of the predicted empirical probability density function (PDF) based on the observed empirical PDF, while for lower or higher values falling outside this range, a constant extrapolation is applied using the correction obtained for the 1st or 99th percentile respectively (Varotsos et al. 2021 and references therein). The difference between the future periods and the reference one are considered robust when the changes for the selected fields at each grid point are found at least three out of five models statistically significant and when the change in the same models is of the same sign. The first criterion is examined by using the 95th percentile confidence intervals as derived by bootstrap. If only one of the criteria is met, the change at the specific grid point is not considered significant.

The Landing page for the 'Long-term projections' Tab is reported in Fig. 9.

1. **Timescale:**
   - Historical Climate
   - Seasonal Forecast
   - Long Term Projections: future scenarios for the 21st century [HERE SELECTED].
2. **Location:**
3. **Type of variables:**
   - *Climate variables:* temperature & precipitation monthly data.
   - *Bioclimatic indicators:*GST, SprR, HarvestR, SU35 WSDI.
4. **Select region:** (Douro Valley or Andalusia [only for the olives/olive oil MED-GOLD service]).
5. **Variable of interest:**
6. **Target period of the projections:**
7. **Select the RCP (Future emission scenario)**: The intermediate (**RCP4.5**) and high (**RCP8.5**) emission scenarios are available corresponding to a global temperature increase of 1.1–2.6 °C and 2.6–4.8 °C, respectively.
8. **Filter: Data or anomalies** It's possible to show the data for the time interval of interest or the deviation of the selected field from the long-term average value over the reference present climate 1971–2000.
9. **Export data:** The maps can be exported in.csv,.netcdf or as images in.jpg.

Summary and conclusions

In the framework of the MED-GOLD project, the scientific and technological partners and end-users have intensively worked in the co-development of an end-to-end wine pilot climate service.

Here a high-level overview of the methodological strategies followed for the implementation and testing of each of the features included in the service has been reported. As a result of this intensive work a pilot wine climate service has been co-created following the end-users needs and requirements.

The MED-GOLD Wine pilot service provides climate information to end-users at different time horizons: historical climate, seasonal predictions and long-term projections through the MED-GOLD Dashboard interactive tool. The products resulting from this service are based on essential climate variables (i.e. mean temperature, maximum temperature, minimum temperature and precipitation), bioclimatic indicators and compound risk indices for the wine business.

The main conclusions achieved during this wine climate service co-development are as follows.

The MED-GOLD wine climate service is able to provide climate

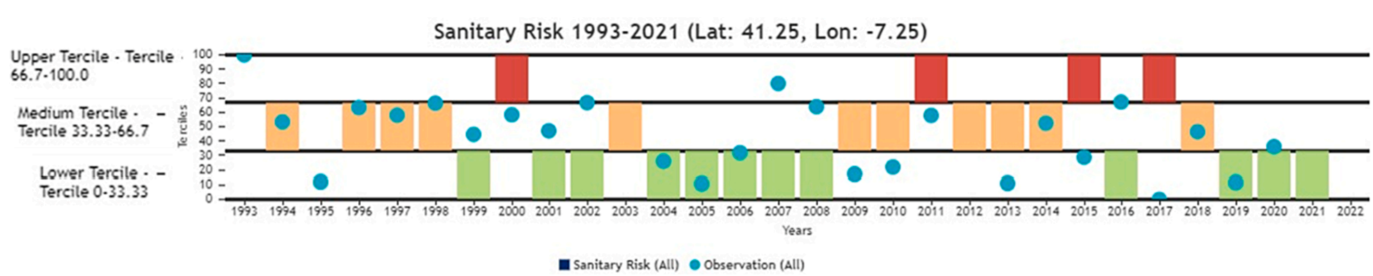

Fig. 8. Time series for a selected grid point in the seasonal forecast tab for Sanitary Risk Index issued in May for the grid point closest to Santa Barbara IPMA weather station.

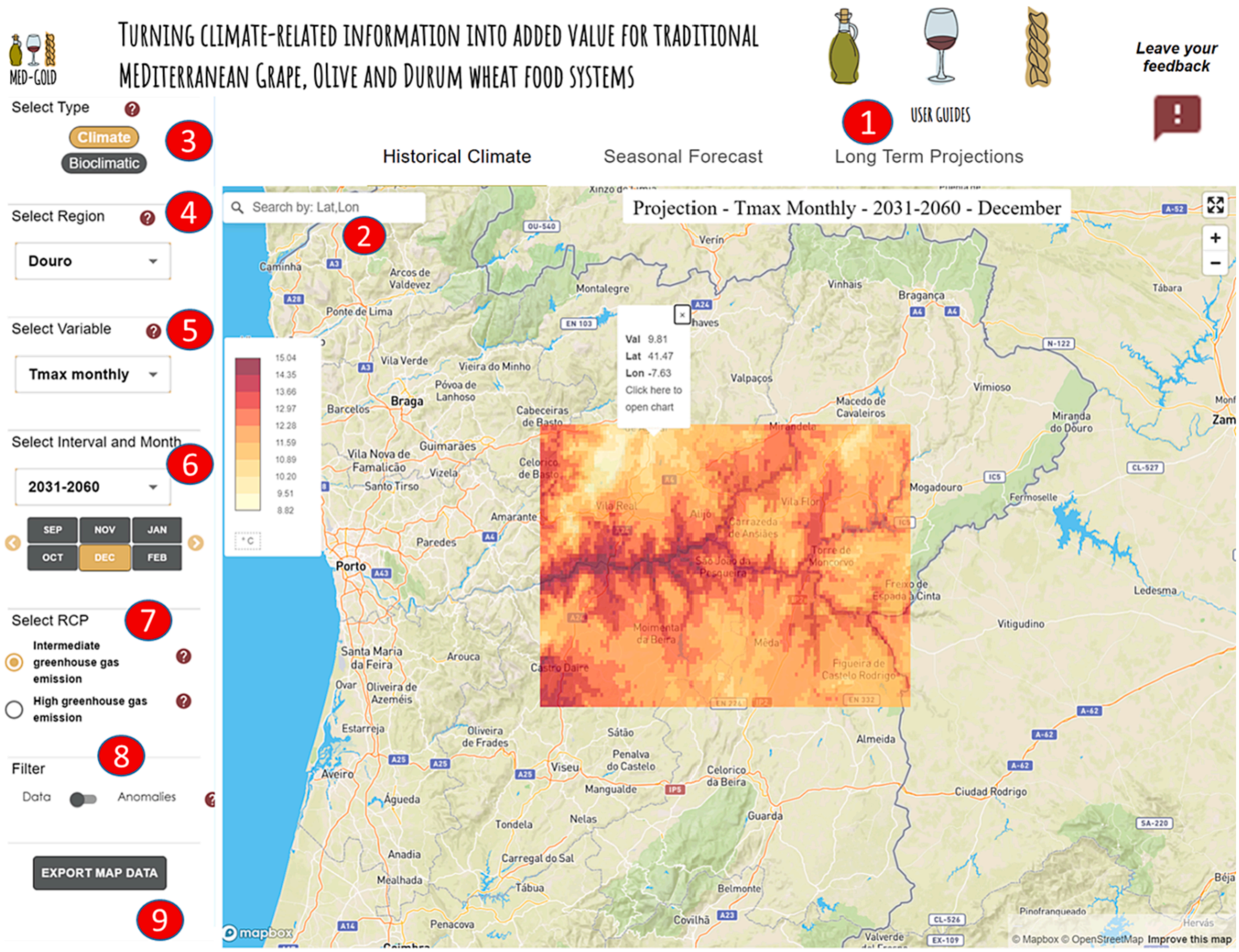

Fig. 9. Landing page for the Long term projections tab: here is reported the foreseen monthly Maximum Temp in December for the period 2013–2060 in RCP 4.5 over Douro region.

information at different time scales that respond to specific questions of the wine sector related to their current needs to plan control on fungal diseases, management of protective treatments, forecast quality of berries and wine, plan for harvest operations or evaluate suitability of varieties in the forthcoming years.

The closer interaction between scientific partners and the wine champion has allowed the identification and calculation of specific bioclimatic indicators of relevance for the wine sector, as well as, the co-design and co-development of two new compound risk indices that can integrate into a single measure the main risk factors that can affect wine production (in terms of quality, quantity and derived inherent value) in the Douro region.

The MED-GOLD wine climate service has already been effective in interacting with users to interpret the probabilistic information delivered by seasonal predictions, highlighting the importance of the reliability associated with these types of predictions.

The methodological workflow adopted for this Pilot service is quite general and it has been also used for the other MED-GOLD services suggesting its replicability over other sectors and other geographical areas.

CRediT authorship contribution statement

Alessandro Dell'Aquila: Conceptualization, Methodology, Writing – original draft, Writing – review & editing, Supervision. **António Graça:** Conceptualization, Methodology, Writing – original draft, Writing – review & editing. **Marta Teixeira:** Data curation, Methodology, Writing – original draft, Writing – review & editing. **Natacha Fontes:** Data curation, Methodology, Validation, Writing – original draft, Writing – review & editing. **Nube Gonzalez-Reviriego:** Data curation, Methodology, Validation, Writing – original draft, Writing – review & editing. **Raul Marcos-Matamoros:** Data curation, Methodology, Validation, Writing – original draft, Writing – review & editing. **Chihchung Chou:** Data curation, Methodology, Validation, Writing – original draft, Writing – review & editing. **Marta Terrado:** Visualization, Methodology, Writing – original draft, Writing – review & editing. **Christos Giannakopoulos:** Data curation, Methodology, Validation, Writing – original draft, Writing – review & editing. **Konstantinos V. Varotsos:** Data curation, Methodology, Validation, Writing – original draft, Writing – review & editing. **Federico Caboni:** Software, Visualization. **Riccardo Locci:** Software, Visualization. **Martina Nanu:** Software, Visualization. **Sara Porru:** Software, Visualization. **Giulia Argiolas:** Software, Visualization. **Marta Bruno Soares:** Conceptualization, Methodology, Writing – original draft, Writing – review & editing. **Michael Sanderson:** Data curation, Writing – original draft, Writing – review & editing.

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.

Acknowledgments

The authors acknowledge project MED-GOLD (Turning climate-related information into added value for traditional MEDiterranean Grape, Olive and Durum Wheat food systems, agreement no. 776467) funded by the European Union. Raul Marcos-Matamoros is a Serra Húnter fellow.

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