H2020-SC5-01-2017

MED-GOLD

Turning climate-related information into added value for traditional **MED**iterranean **G**rape, **OL**ive and **D**urum wheat food systems

DELIVERABLE 3.1

REPORT ON THE TWO CASE STUDIES AT SEASONAL- AND LONG-TERM TIMESCALES FOR THE WINE SECTOR

This project has received funding from the European Union's Horizon 2020 research and innovation programme under gran agreement No 776467.

DOCUMENT STATUS SHEET

Deliverable Title	**Report on the two case studies at seasonal- and long-term timescales for the wine sector**	
Brief Description	This document reports on four Focus Groups conducted with process managers of a wine company (SOGRAPE VINHOS) having an important grape and wine operation in the Douro Wine Region to get a feedback on the importance of prior knowledge of future weather, at two different time scales, in decision making. From this exercise, it became clear that services would be important and considered in decision-making, making a positive contribution to the company's economic and environmental performances, provided they have an acceptable probability of prediction.	
WP number		WP 3
Lead Beneficiary	SOGRAPE VINHOS PORTUGAL	
Contributors	*Marta Teixeira, Natacha Fontes, António Graça*	
Creation Date	25/01/2018	
Version Number	1.6	
Version Date	30/05/2019	
Deliverable Due Date	31/07/2018	
Actual Delivery Date	31/07/2018	
Nature of the Deliverable	R	*R - Report* *P - Prototype* *D - Demonstrator* *O - Other*
Dissemination Level/ Audience	CO	*PU - Public* *PP - Restricted to other programme participants, including the Commission services* *RE - Restricted to a group specified by the consortium, including the Commission services* *CO - Confidential, only for members of the consortium, including the Commission services*

REVISION HISTORY LOG

Version	Date	Created / Modified by	Pages	Comments
1.0	16-07-2018	SOGRAPE	5	Initial Draft
1.1	19-07-2018	SOGRAPE	10	Working Version
1.2	26-07-2018	SOGRAPE	16	Working Version
1.3	30-07-2018	SOGRAPE	28	Submitted for peer review
1.4	13-08-2018	SOGRAPE	28	Updated after interaction with the project mailing list
1.5	23-08-2018	SOGRAPE	27	Final after peer review
1.6	31-05-2019	SOGRAPE	29	Final after PO review

TABLE OF CONTENTS

LIST OF TABLES AND FIGURES

EXECUTIVE SUMMARY

Besides being the historical origin of many world-famous wines (Champagne, Porto, Chianti, Rioja, Santorini, etc.) the EU is one of the major world players in the grape and wine business being the origin for 70% of global wine exports, the wine sector employing 20% of its total agricultural labour.

The production of grapes and wine is heavily affected by weather and climate, and therefore is highly vulnerable to climate change. During the 21st century, there is an increased risk of drought, especially in the Mediterranean region, with increases in temperature in winter (reducing frost risk) and during growing seasons (reducing yields and disrupting grape aptitude for quality wines), which are relevant for viticulture.

Wine phenology, quality and productivity depend on regional climate, at both local scale (mesoclimate: influenced by altitude, wind, slope and water proximity) and micro scale (influenced by vine spacing, soil and canopy management). Climate on a regional scale has, so far, been the focus of assessing the impact of climate change. At the local level, the impact of site selection and vineyard management is higher, its consideration is important for adaptation to climate change. Arguably, the Douro Wine Region of Portugal, home to world renowned Port wines, is one of the European wine regions where climate and climate change has for longest been perceived as having a critical impact in the business sector's economics. It is thus an ideal laboratory for climate service development and deployment.

MED-GOLD seeks to create innovative climate services for risk management based on seasonal and long-term climate predictions, enabling mitigation by adapting to these changes, enhancing activities linked to agricultural management with supporting information and policies (for example: The Paris COP21 Agreement). These services will be applied at an early stage to the farming of olives, grapes and durum wheat, which, after processing, become respectively olive oil, wine and pasta - the basic products of the Mediterranean diet.

To assess user needs for specific climate services in the grape and wine sector, four Focus Groups were conducted with process managers of a wine company (SOGRAPE VINHOS) having an important grape and wine operation in the Douro Wine Region to get a feedback on the importance of prior knowledge of future weather in decision making. From the results of these Focus Groups, it became clear that access to such services with acceptable prediction probabilities would be important and considered in decision-making, making a positive contribution to the company's economic and environmental performances.

With this deliverable, the project has contributed to the achievement of the following objectives (DOA, Part B Table 1.1):

No.	Objective	Yes
1	To co-design, co-develop, test, and assess the added value of proof-of-concept climate services for olive, grape, and durum wheat	X
2	To refine, validate, and upscale the three pilot services with the wider European and global user communities for olive, grape, and durum wheat	
3	To ensure replicability of MED-GOLD climate services in other crops/climates (e.g., coffee) and to establish links to policy making globally	
4	To implement a comprehensive communication and commercialization plan for MED-GOLD climate services to enhance market uptake	X
5	To build better informed and connected end-user communities for the global olive oil, wine, and pasta food systems and related policy making	X

1. INTRODUCTION

1.1. PURPOSE AND SCOPE

The European Union represents 45% (3 362 000 ha) of the global vineyard area, 63% (27.4 bn L) of global wine production, 52% (24 bn 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). 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, 2017) while ranking as the 20th in terms of deaths caused by mental and behavioural disorders due to use of alcohol, all ages and genders confounded (EUROSTAT, 2015).

Grape and wine production is strongly affected by weather and climate and is therefore highly vulnerable to climate change. In Portugal, the wine sector plays an important role in economic growth and stability (Fraga et al. 2014). The Portuguese mainland is divided into 12 wine regions, some world famous as Porto-Douro, Minho-Vinho Verde and Alentejo. Recent studies of Portuguese wine-growing areas (Fraga et al., 2014) reveal the fragility throughout the whole country and wine regions. In fact, climatic characteristics provide different wine growing characteristics in each region, along with geomorphological aspects, experienced management decisions and numerous native wine grape varieties (343 different vine varieties authorized in Portugal for wine production - Ordinance no. 380/2012), contributing to inter-annual oscillation in the quantity of wine produced.

The effect of climate change on grape phenology has been the subject of many studies (Jones et al., 2012, Koufos et al., 2014, Fraga et al., 2014a, Fraga et al., 2015). Despite man's interference in the ecosystems created in wine-growing areas, because of wine-growing practices, it is well-known that the climate exercises great control over the crop. Global climate change will necessarily affect local climate and grape phenology, grape quality and yield, both very dependent on annual climate at local scales. Climate change is expected to accelerate phenological processes of the grapevine. Indeed, projections on grape maturity and harvest data reported expected advances over several years for many varieties across different winegrowing regions. 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 (in 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 authors (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 (Jones et al., 2005, Nicholas et al., 2011).

Portugal is a country with a strong wine production and it’s one of the largest wine producers in the world (OIV report, 2017). It has more than 30 wine regions bearing PDO (Protected Designation of Origin), the Douro Wine Region (DWR) being the oldest demarcated and regulated wine region in the world. Viticulture in there, dates to at least 2000 years ago, but its wines gained international fame in 1756 when the Port wine PDO was created by official law. Since then, the region is known worldwide for the excellence of wines produced there.

The vineyards of Douro, located in a mountainous area in north-eastern Portugal, have complex geo-morphology, creating multiple meso- and micro-climates. The region extends over a length of 100km following the river Douro, being mostly characterized by steep valleys and steep slopes. Vineyard installation is made up to 700 meters 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 (Tratado de viticultura, 2015).

The vineyards considered appropriate for Port production are selected according to quality criteria based on a scoring method and ranked according to a scale of quality (A - best potential to F - least potential). This method considers soil, climatic and agricultural parameters, which are important in determining the quality potential of each vineyard. Grapevines must be at least 5 years old before they can be considered able to produce Port (IVDP, https://bit.ly/2uYryMm).

On average, about half of the region’s grape production is used for Port on any given year, and other wines are also produced there. Of those, the dry reds, whites and rosés produced with Douro PDO have gained international acclaim in recent decades, becoming another very important source of income for the region.

Due to the mesoclimate differences in the Douro, influenced by altitude and distance to the sea, the Douro is subdivided into three sub-regions: *Baixo Corgo, Cima Corgo* and *Douro Superior* (Figure 1).

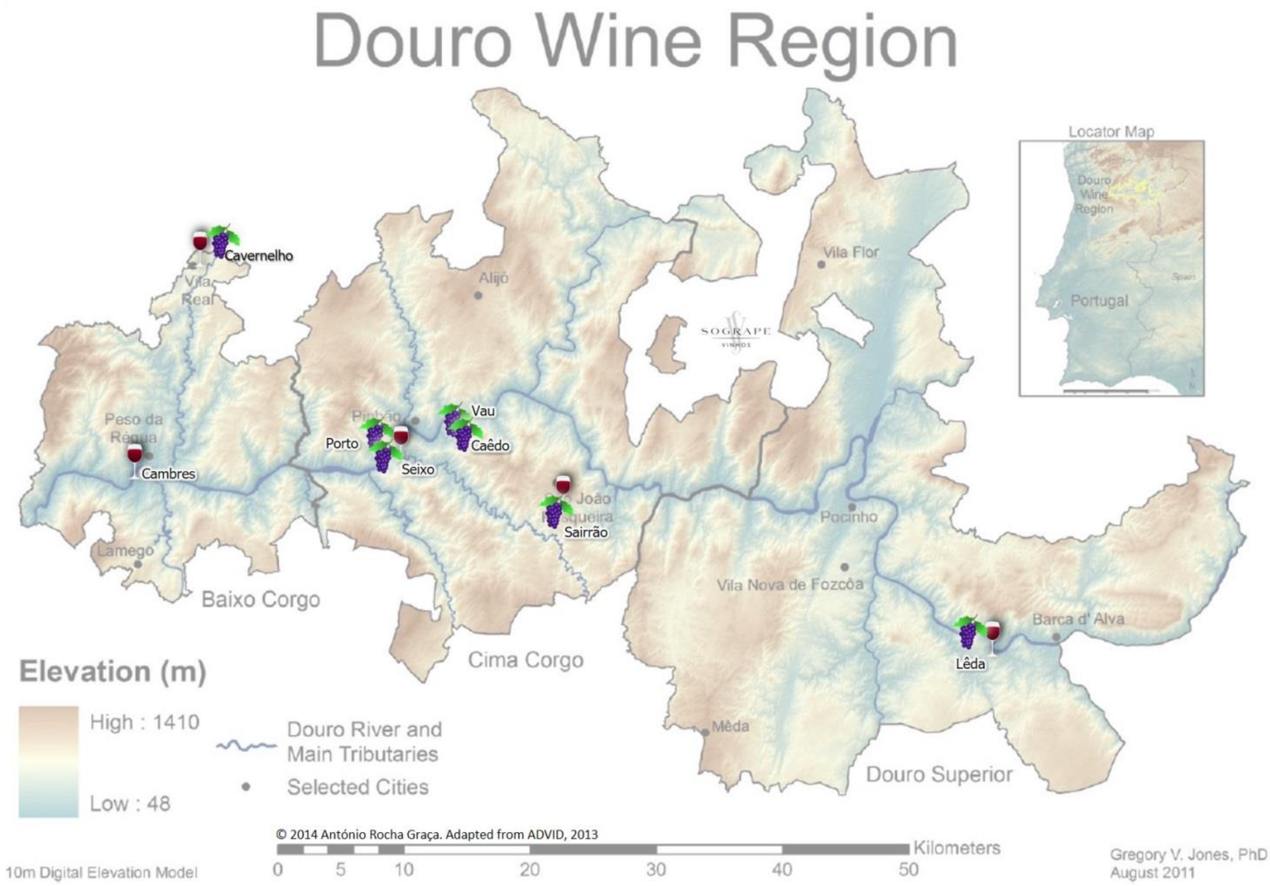

Figure 1 - Topography of the Douro Demarcated Region with its subregions (Jones,2012) and indication of SOGRAPE's properties (bunch) and wineries (glass).

The *Baixo-Corgo* climate is characterized by a maritime influence, translating into zones with more precipitation and cooler temperatures relative to other sub-regions. These characteristics make *Baixo-Corgo* the most fertile area where wines of excellence have been produced the longest. These climatic characteristics make it the sub-region with the largest area dedicated to vineyards.

In *Cima-Corgo* there is a decrease of precipitation and increase of temperature as compared to *Baixo-Corgo*. The finest Ports and Douro PDO wines are produced, in general, in *Cima-Corgo*, owing to the climatic conditions and the rugged orography.

The *Douro-Superior* is characterized by a warm dry Mediterranean climate. Although it is larger than the other sub-regions, the wine-growing area is smaller. However, it has less steep slopes, allowing greater ease of cultivation, which is the reason why there has been a recent increase in the installation of vineyards. Associated with its typical Mediterranean climate, Port and Douro wines of great quality are produced (Tratado de Viticultura, 2015).

Despite the grapevine's great adaptability to environmental conditions (climate, soil and geomorphology), the economic viability of any vineyard is determined by the local meso- and micro-climate. The effects of climate change on phenology and grape production have been widely studied and discussed by several authors (Jones et al., 2012, Tomasi et al., 2011, Koufos et al.2014, Fraga et al.2014a, Fraga et al.2015). Climate change will affect vine phenology, grape quality and yield, both of which are highly dependent on annual climatic variability. Owing to the warming of temperatures worldwide, an advance in the phenological stages of the grapevine is expected. Koufos et al. (2014) show that the impact of climatic changes on phenological stages indicates an anticipation in the maturation of grapes and in the date of harvest over the years, regardless of grape variety and wine region.

Therefore, despite the grapevine's high adaptability, we can expect that climate change will have an impact on its yields and quality of grapes produced, which in turn will impact wine production and quality and affect the economics of wine production. Aiming to mitigate and adapt the wine sector to climate change, MED-GOLD proposes to develop climate services providing information with improved reliability and usefulness, when compared to what is available today.

The DWR, thus provides an ideal diversity of situations for evaluating the added-value of climate services for viticulture, reason for which it was chosen as the target to develop the project pilots. It is also the region where the longest data series for climatic and non-climatic data are available. The resulting services and insights can be easily applied to other wine regions, in Portugal and other countries.

1.2. ACRONYMS

Table 1 - List of acronyms used in the document and their meaning

Acronym	Definition
EU	European Union
COP21	21st Conference of the Parties to the United Nations Framework Convention on Climate Change
DWR	Douro Wine Region
FG	Focus Group
IVDP	Instituto dos Vinhos do Douro e Porto (Port and Douro Wines Institute)
MED-GOLD	Project “Turning climate-related information into added value for traditional MEDiterranean Grape, Olive and Durum wheat food systems”
OIV	Organisation Internationale de la Vigne et du Vin (International Organization for Vine and Wine)
PDO	Protected Designation of Origin
WP	Work Package

2. MED-GOLD

The MED-GOLD project aims to demonstrate a proof of concept for climatic services in the agricultural sector for three basic crops of the Mediterranean diet: grapes, durum wheat and olives.

The Mediterranean basin has been identified as one of the areas of the planet where climate change will be most evident, threatening its extremely rich biological and cultural diversity, increasing vulnerability to natural hazards including biological invasions (Agnoletti & Emanueli, 2016).

The goal of MED-GOLD is to make accessible the use of climatic data and state-of-the-art forecasts for seasonal and decadal timescales. To achieve this objective, MED-GOLD has the contribution of three world leaders in the three basic products of the Mediterranean diet - SOGRAPE (wine), DCOOP (olive oil) and BARILLA (durum wheat) - which will co-develop climate services with value for the three production processes. The participation of these three companies will catalyse and stimulate the recruitment of users across Europe. These three companies are responsible for identifying what kind of information they need from climate models to successfully adapt their cultural practices and industrial processes to climate change. Those insights will be used to create new climate services by scientific partners with a great deal of experience in academic research and in the development of mechanisms that respond to users' needs (ENEA, BSC, CNR, CCI, MetOffice, NOA, UMNG, UNIVLEEDS, UTH). The consortium also includes private companies, some of which are pioneers in climate services (Beetobit, EC2CE, HORTA, GMV).

In the case of the grape and wine sector, to understand what influence prior knowledge of climatic conditions for the next months, (seasonal forecast) or coming years (decadal forecast) may have in decision-making inherent to the productive process, SOGRAPE hosted four different thematic Focus Groups (FG) with process managers whose function is impacted by climate. The FG method was chosen because of the freedom it infuses on participants, when addressing "key issues", allowing in a relaxed way access to information and answers that would otherwise be difficult to obtain.

3. Appraising needs and critical decisions

3.1. FOCUS GROUP

Interviews were jointly prepared by SOGRAPE and University of Leeds MED-GOLD team members according to guidelines described in D1.6. The interviews were conducted in Portuguese, on the 2nd and 3rd of May (2018) at SOGRAPE's facilities, with the maximum duration of 1h30. At the end of those interviews, participants were asked to fill out an inquiry to evaluate the event.

The SOGRAPE's MED-GOLD team members, besides acting as specialized end-users also play a leading role in establishing the link between wine sector end-users and the MED-GOLD scientific partners (Figure 2).

Figure 2 - MED-GOLD team members present in the FG.

Being vertically integrated, the company covers the whole grape and wine production chain on which, the importance and influence of climatic conditions are critical. Based on this, four distinct groups were selected to address different identified thematic areas (Table 2), considered critical for the company's business.

Table 2 - Focus Groups and respective thematics.

Focus Group	Thematic Area
1	Strategy
2	Viticulture Management
3	Oenological Management
4	Stocks Management

The selection of SOGRAPE'S participants on the FG was based on their role and responsibility level within the company (Table 3).

Table 3 - Number of participants in FG by position within the company.

Position	Number of elements
Chief Executive Officer	1
Administrator	1
Director of Viticulture	1
Director of Oenology	3
Purchasing Manager	1
Oenology Technician	1
Operating Manager	1

Participants were inquired regarding the extent they would use seasonal and decadal forecasts in decision-making for the company processes they manage. Specific process decisions were discussed in detail during the interviews (Table 4).

Table 4 - Process decisions analysed in each Focus Group.

Focus Group	Process decision	Type of forecast
1	- Choice of region and site for establishment of new vineyards - Choices of grapes varieties for planting	Decadal
2	- Choice of grapevine's rootstock and clone for planting - Definition of training and pruning system - Cropping operations' planning and management - Management of agricultural machinery according to operational planning	Seasonal and Decadal
3	- Maturation control planning - Setting harvest dates	Seasonal
4	- Stock Management (products and consumables for viticulture and winemaking)	Seasonal

The topics covered are transversal to all areas of wine production in Portugal, but DWR is the largest, having diverse implications in several areas of society. The following table (table 5) exemplifies average values for SOGRAPE properties in the Douro in 2016 / 2017.

Table 5 - Fundamental data of SOGRAPE's grape production in Douro Wine Region(average 2016-17)

Parameter	Value
Area Vineyard (ha)	540
Grape production (kg)	1 717 670
Total cost of grape production (€)	1 786 601
Labour involved in viticulture (hours)	55 861
Cost of machinery (€)	43 625
Subcontracting (€)	656 864

In 2017 a production loss of 3,5% when compared to 2016 was recorded because of severe drought coupled with high temperatures. An increase in the cost of production by 4% was also observed between both years. Because of the generic loss of production, the price of grapes in the local market for DOP Douro red wines surged by close to 30%. Labour expenditure in vineyards was 8,4% higher in 2016 because of the manual work involved in protecting grapevines against sanitary risk. Machinery costs (amortization, fuel and maintenance) spiked by 30% in 2017 due to the difficult environmental conditions caused by drought increasing the need for repairs and maintenance.

In the following section the topics of each focus group (FG) will be discussed.

3.2. THEMATICS ADDRESSED DURING FG

With the purpose of framing and clarifying the technical terms discussed in each FG (Table 2) and their importance in the productive process and, consequently, in the respective decision-making, a summary is presented below.

3.2.1. STRATEGY

In the FG dedicated to the strategy, subjects such as vineyard installation and choice of grape varieties were discussed.

3.2.1.1. VINEYARD INSTALLATION

The installation of a vineyard involves a whole process of analysis and weighting about siting, considering, the purpose of satisfying profitability through meeting production and quality needs, for at least 30-40 years. The analysis considers parameters such as climate, soil fertility and health status, and other related issues such as slope, sun exposure and soil type, among others.

3.2.1.2. CHOICE OF GRAPEVINE VARIETIES

The choice of rootstock and grape variety(ies) are important decisions associated with the installation of a vineyard. Rootstocks are necessary as in most European wine areas, the presence of a noxious insect (*Phylloxera*) renders planting of *Vitis vinifera* (the European species) on its own roots impossible. European grapevine scions need therefore to be grafted onto rootstocks of American grapevine species or hybrids which are resistant to the pest.

The choice of rootstocks is directly linked to soil type, fertility, water availability, chemical and biological characteristics of the soil and the climate of the region, with the purpose of achieving production and quality objectives. However, the choice of rootstock must also take into account the influence it can have on the scion's variety, namely in terms of vigour, productivity, maturation and qualitative characteristics of the grapes. The choice of grape variety for a given region is also important for the wine to be produced. Varieties that best adapt to the conditions of the region such as: soil, sun exposure, altitude and climate are required. Consumer preference may also play a role when selecting grape varieties.

3.2.2. VITICULTURE MANAGEMENT

In the FG for vineyard management, some of the issues discussed are described below.

3.2.2.1. PRUNING

Pruning is an intervention that applies to the grapevine in two distinct stages:

- winter pruning, takes place during the vegetative rest phase, and

- green pruning carried out in the active phase of the vegetative cycle, when necessary.

Pruning defines the shape and size of the vine, influencing the balance between growth and yield, quantity and quality. Pruning consists of selecting buds (structure of the vine) and leads the vine (branches) according to objectives of both quantity and quality. Winter pruning should be done between leaf fall and bud break (beginning of vine shoot after vegetative rest) - when the vine is not vegetating, therefore not jeopardizing the reserve content in the plant. Sometimes, for climatic adaptation, late pruning is applied, in regions where frost frequently occurs, for protection of spurs (young shoots on the vine, at the beginning of vegetative growth).

3.2.2.2. TRAINING SYSTEM

Training allows for spatial management of the vine, guiding it in the way it is intended, giving it a desired shape, setting limits of height and orientation for the leaf canopy. This orientation of the plant has the purpose of taking advantage of the climate, allowing for aeration of the plant, reducing conditions favourable to the appearance of diseases, and increasing the area of radiation absorbed by the plant (helping its development - biological processes, among them photosynthesis). For the choice of a given training system, different climatic parameters such as solar radiation, wind, temperature and water capacity of the soil are considered.

In the vegetative state of the vine, other interventions are performed, indispensable to the adjustment of the plant to the conditions induced by the climate. These interventions take place throughout the vegetative cycle (period between bud break and harvest), to reduce the risk of diseases (aeration) and increase the production and quality of the grape (balance between leaf area and grape production). These interventions represent a major cost in the production of wine because of the need to intensively use machinery and labour for very specific periods of time. The interventions take place throughout the entire vegetative cycle, at an initial stage in the removal of shoots and leaves, and, at a later stage in the selection of the bunches to be developed. All of these interventions are conditioned by the current climatic conditions.

3.2.2.3. PEST MANAGEMENT

There are several diseases that affect the grapevine that are favoured by specific climatic conditions. These diseases may be of fungal origin, namely downy and powdery mildew, among others, bacterial in origin, or pests – insects, among others.

Powdery mildew (*Erysiphe necator*) is a disease widely known in the wine community. The vines are carriers of the fungal spores. Certain climatic conditions, such as high humidity and mild temperatures, together with a lack of aeration, promote the development of powdery mildew. Mildew, when it emerges at the stage of vegetative development, damages the grapes, ultimately deteriorating the quality of the wine and its aroma. The Douro Wine Region is known for its susceptibility to powdery mildew. The risk is controlled with adapted training systems and effective canopy management allowing aeration of the plant. Fungicides are also used; several active substances differ in the degree of persistence and form of action. The exact type is chosen according to the phenological state of the plant and severity of the infection. Usually, control is managed in an integrated protection system, like the one that SOGRAPE adopts in all its vineyards, following tight rules regarding the number of applications and quantities for the best balance possible between protection and minimization of environmental impact.

Downy mildew (*Plasmopora viticola*) develops in spring, when vine tissues are tender and because of high humidity and warm temperatures, (Rule of Three-Tens: 10 mm of precipitation, 10 ℃ of air temperature and 10 cm of shoot length). In addition to climate conditions conducive to its development, situations such as poor aeration, which increases humidity and reduces exposure to sunlight, can cause development and spread of downy mildew. This fungus requires continuous control of the vineyard for the identification of contamination outbreaks and swift control. The forms of control include chemical interventions (application of fungicides) to increasing soil drainage next to the vine - poor drainage next to the plant promotes the spread of the fungus.

The use of chemicals can be carried out in two different ways, preventively or curatively, being applied before or after infection, respectively. The durability of its application varies according to the weather conditions. The expected effect is lost after 25mm of precipitation, when a repeated application is necessary (Tratado de Viticultura, 2015) with economic and environmental costs.

There are other diseases caused by fungi such as: grey rot, acetic rot and other grapevine rot, black rot, escoriosis, *Eutypa*, trunk diseases complex, root rot. They all have diversified methods of control and attack different areas of the grapevine.

In addition to diseases caused by fungi, the vine is subject to other biotic stresses with diverse origins, such as diseases caused by bacteria (bacterial necrosis, Crown Gall, Pierce's disease), and by viruses and phytoplasmas (grapevine fanleaf virus, foliar vine foliar disease, stem pitting, fleck virus, «flavescence dorée» among others), and damage caused by pests (green leafhopper, grape moth, mites, among others). All require different methods of control, of biological, physical and chemical in nature, but, in all cases, greatly conditioned by weather conditions that, associated with the fragility of the vine, can become epidemic and represent severe problems that will affect both the quality and quantity of the grape produced, translating into economic losses for producers.

3.2.3. OENOLOGICAL MANAGEMENT

3.2.3.1. THE HARVEST

In FG3, the base thematic was the harvest. Harvesting is one of the most complex operations in the production process. It starts when grapes reach the desired degree of ripeness which is determined based on physicochemical analysis of sugars, organic acids, polyphenols and aromatic precursors, which vary between varieties with time. The setting of the harvest date is, therefore, a complex process. There are other important factors that affect the harvest date, which include:

- weather conditions, which can anticipate or delay the harvest;

- risk of diseases or pests;

- availability of manpower as well as operational planning (availability of winery capacity to receive grapes, harvesting machines, transport, etc).

This set of variables is evaluated by the winemaker to mark the date of harvest. In days preceding harvest, factors such as temperature variation, gradually or suddenly, chemically influence the composition of the must (the juice obtained from crushed grapes), because of its impact on both the primary and secondary metabolism of the grapevine. Similarly, the occurrence of precipitation, which may involve the dilution of the constituents of the berry or the sanitary quality of the grapes, will condition the final composition and, therefore, the quantity and quality of produced must.

"É na vinha que se faz o vinho."

(It is in the vineyard that wine is made)

Usual saying describing perfectly the importance of grape quality in the final product - wine. The choice of harvest date is, thus, a critical moment that will reflect on the type and style of wine and its final quality. Waiting for the right moment between balance / equilibrium of the different compounds which will be responsible for the sensory characteristics of the final wine, entails high risks that can compromise both production quantity and grape quality, putting at risk one year of vineyard work.

3.2.4. STOCK MANAGEMENT

Stocks of products for both viticulture and oenology operations are managed by process owners together with Direction of Purchasing. These products are fundamental for the correct execution of important processes in the company. Typical examples are fertilizers, trellis wires or pesticides for the vineyard or oenological products, processing aids or additives for musts and wines.

To avoid process disruption, it is essential to have sufficient stocks in house or delivered in time, however, larger than needed stocks represent unnecessary capital invested in stock, something that should be avoided. Furthermore, some products (pesticides, yeasts, etc.) have validity dates which render them unusable if not used before.

For some products, market price oscillation occurs due to demand and supply dynamics and it is, naturally, possible to negotiate better deals when acquiring larger amounts.

Advance knowledge of required quantities to supply production processes just-in-time translates into better cost efficiency and, consequently, better economic outcomes. Good stock management becomes, thus, an indirect but important consequence of climate impacts in the business of grape and wine production.

3.3. CLIMATE CONDITIONS AND INDICES

In addition to the effect on the sanitary condition of the vineyard, as explained above, climate has a strong impact on growth and development of the grapevine. The occurrence of extreme weather events is one of the main trends in recent climate change. As an example, frosts can have high impacts on grape production. When they occur in spring, during full vegetative development, they destroy the new shoots, together with leaves, inflorescences, etc. The occurrence of high impact weather events such as thunderstorms and hail also damage vines, sometimes affecting the year's crop, depending on severity of the event. High temperatures and strong direct radiation at an advanced stage of the vegetative cycle lead to scorched leaves, exposing berries to the sun and causing them to dehydrate and / or burn. Temperatures over 40°C and low relative humidity lead to extreme thermal stress of the vine, with continuous water loss (these conditions are very common in DWR, Douro Superior). Above 35°C, photosynthesis stops, arresting the production of sugars that are critical to the maturation of the grape berry. Water stress and water deficit, depending on the vegetative state, will have different effects on the grapevine. At the beginning of the vegetative cycle a lack of water causes the plant to have a weak development relative to the number and size of inflorescences. During the vegetative cycle, when under water scarcity, the plant undergoes morphological alterations such as reduction of leaf area, reduction of growth, and senescence (aging) of the basal leaves, reducing transpiration losses, among others (Boyer et al., 1997). In many wine-growing regions of southern Europe, higher temperatures induce an increase in evapotranspiration by the grapevine, generating a dry growing cycle, which induces high water deficit at an early stage (Malheiro et al., 2010). This situation requires adaptation of cultivation practices, such as irrigation systems to avoid problems of yield reduction and loss of quality for winemaking (Ojeda, 2010).

In the Douro, as in other regions with a Mediterranean climate, availability of water during summer is a limiting factor for the growth of the vineyard and the quality of harvested grapes. In this region, vines experience water deficit soon little after bud break (Alves et al., 2006a; Alves et al., 2006b; Malheiro et al., 2007).

Climate being an important driver of value for the production of wine, the company has for several years developed research work in this area: Graça et al. (2011), Fontes & Graça (2013), Fontes et al. (2015), Fontes et al. (2016a), Fontes et al. (2016b), Photiadou et al. (2017). Among several other results, these works demonstrated that climate influences phenology, quality and productivity of grapevines. Fontes et al. (2016a), using an analysis of an extensive set of climatic indices (Table 6) for different wine-growing areas in Portugal (Vinhos Verdes, Dão, Alentejo and Douro), have shown that some climatic indices have strong correlation with yield and harvest date, effectively separating regions in a statistical model. The models need further validation and it is being updated as more data becomes available.

The Douro region separation from others was noted for its high correlations with climatic indices such as GDD, GST and WSDI.

Table 6 - List of climate indices relevant for winegrape production. These climate indices include: primary climate parameters, bioclimatic (Tonietto and Carbonneau, 2004) and extreme climate indices, the latter computed according to the ETCCDI tool (Jones and

Variable	Description	Units
Primary climate parameters		
CH	Total hours of chilling: Winter count of hours when TN (daily minimum temperature) ≤ 7°C	Hours
TR	Annual total precipitation	mm
WintR	Winter total precipitation	mm
SprR	Spring total precipitation	mm
SumR	Summer total precipitation	mm
Bioclimatic indice		
GST	Growing Season temperature	°C
HI	Huglin index	°C units
GDD	Growing degree-days	°C units
CI	Night cold Index – Tmin last month of maturation	°C
Extreme climate indices		
FD0	Number of frost days: Annual count of days when TN (daily minimum temperature) < 0°C;	Days
SU25	Number of summer days: Annual count of days when TX (daily maximum temperature) >25°C:	Days
SU35	Number of heat stress days: Annual count of days when TX (daily maximum temperature) >35°C:	Days
TR20	Number of tropical nights: Annual count of days when TN (daily minimum temperature) > 20°C;	Days
TXx	Monthly maximum value of daily maximum temperature;	°C
TNx	Monthly maximum value of daily minimum temperature;	°C
TNn	Monthly minimum value of daily minimum temperature;	°C
TX10p	Percentage of days when TX < 10th percentile	%
TN10p	Percentage of days when TN < 10th percentile	%
TX90p	Percentage of days when TX > 90th percentile	%
TN90p	Percentage of days when TN > 90th percentile	%
WSDI	Warm spell duration index: Annual count of days with at least 6 consecutive days when TX > 90[th] percentile	Days
CSDI	Cold spell duration index: Annual count of days with at least 6 consecutive days when TN < 10[th] percentile	Days
DTR	Daily temperature range: Monthly mean difference between TX and TN;	°C
RX1day	Rx1day, Monthly maximum 1-day precipitation;	mm
RX5day	Rx5day, Monthly maximum consecutive 5-day precipitation;	mm
SDII	SDII, Simple precipitation intensity index: the daily precipitation amount on wet days, (wet day PRCR ≥ 1mm	mm/day
R10	R10mm, Annual count of days when PRCP≥ 10mm;	Days
R20	R20mm, Annual count of days when PRCP≥ 20mm;	Days
CDD	CDD, Maximum length of dry spell, maximum number of consecutive days with RR < 1mm;	Days
CWD	CWD, Maximum length of wet spell, maximum number of consecutive days with RR ≥ 1mm.	Days

4. RESULTS

In this section, the insights obtained on the process decisions listed in table 2 are presented, organized by FG.

"Access to a higher quality, higher resolution climate service is paramount to the industry strategy"

In the first FG, who considered the company's strategy, topics under discussion were related to company management and its development, mainly in terms of purchase of new vineyards and choice of future regions as well as grape varieties to be planted.

Knowing climate trends beforehand was important for the selection of grape varieties and ordering of plants from nurseries. Currently, there is a great diversity of grapevine varieties; furthermore, for certain varieties there is also great clonal diversity modifying characteristics, such as heat resistance and acidity, among others. Thus, it is important to know the trend of climate change in relation to temperature and precipitation, as a new vineyard is a significant and long-term investment. In addition to general temperature trends it is important to quantify the magnitude of variation, as a change of 0.5°C to 2°C already conditions the choice of varieties. It is also critical to know the local trend of water availability. Absence of water by itself is not a problem, provided there is a feasible possibility of establishing a sustainable irrigation system.

Consumer trends for a wine (white, rosé or red) conditions choice and planting of varieties. It will be important to understand where is best to plant new vineyards to obtain the wine consumers are used to drink in a situation where predicted climate change no longer will allow it as it does under current conditions

Finally, the key decision-makers invited for this group stated that they are currently using climate trend products available for decision making, but that it would be vital to have access to higher quality services with higher temporal and spatial resolution. It would be important to obtain monthly average values of maximum and minimum temperatures and precipitation. For the purpose of long-term investment, the long-term (decadal) forecasts were the most relevant. When questioned about the reliability that climate forecasts would need to have to influence their decisions, all were unanimous in defining 80% as the minimum, since the decisions involve large capital investments.

"Early knowledge of climate will allow for more efficient management of both products and manpower"

In the second FG, the process decisions were related to vineyard management.

The process of vineyard management is executed with detail to the individual vineyard block (usually a continuous cultivated area, defined by roads, using the same variety and training system) to meet winery specifications, both in terms of quality and quantity, needed to satisfy market demand. Each type of wine and region needs specific procedures, for example, the type of pruning, which differs between regions. The type of pruning is conditioned by the vineyard's production objectives in function of adaptation to local climate. Inherent to pruning is the training of the grapevines, whose initial phase takes 3-4 years to be completed (time for the plant to achieve production size), thus emphasizing the importance of access to timely climate services.

Additionally, one of the main advantages of having access to seasonal climate forecasts is the economic gain to be derived from anticipating and managing treatments in the vineyard. FG members stated they currently use 4 to 5-day lead-time forecasts, which allows them to manage their spraying more efficiently by avoiding product loss from subsequent rainfall.

Earlier and more accurate knowledge of seasonal climate will allow for more efficient management of both spraying products and manpower, currently executed with reference to climatology (both intuitively and with 30-year climate series available from the national weather service).

That increase in efficiency would translate as better management of spraying against diseases, supporting vineyard development or even generating earlier strength of grapevines against humidity-driven diseases (fungal) in more sensitive phenological states by acting more proactively and less reactively, as it is currently the norm.

The same goes for setting harvest dates. It is possible to prepare berries for earlier picking, if there are high probabilities for precipitation to occur in the month harvest is scheduled. This prior knowledge may imply saving an entire work season, the vineyard being an annual crop, which can be lost in intense rainy days at harvest time (as was the case in 1993).

Labour management would also benefit from accessing forecasts earlier, by managing and assigning functions / tasks in advance, according to expected weather development, to internal staff. This knowledge would also allow for better management of subcontracted labour, avoiding the stress coming from the sudden need for experienced staff to work on the vineyard against the clock to save grapes from bad weather. This stress is fostered by the simultaneous need of all winemakers from different producers in the region trying to save their grapes and struggling with the scarce labour force available. Prior knowledge for probability of bad weather would also allow for better negotiating with subcontractors in a timely manner and achieving better deals with large impacts on budgets and costs.

Earlier knowledge of seasonal climate probability would also have an ecological side when it comes to herbicide application during winter and early spring, by allowing for more efficient management of this operation as well as a better choice of active substances, avoiding unnecessary soil and groundwater contamination due to the risk of precipitation and washout.

Regarding decisions on rootstocks and varietal clones, users admitted that, although they do not consciously consider expected climatic conditions and their impact, in the case of Douro Superior sub-region they already select rootstocks that are better suited to higher temperatures, since the trend for temperature increase there has been constant in recent years. However, they emphasized that the choice of rootstock is more conditioned by the type of soil than by climate. Conversely, vine management operations decisions are more dependent on the climate of that region.

Finally, all participants agreed that if they had a forecast with a reliability of 70%, they would take it into account for decision making, emphasizing that a seasonal forecast at 6 months lead-time would be relevant and important from the point of view of all processes addressed in this Focus Group.

“Timely knowledge of climate can save an entire production”

FG3 discussed the oenological aspect of grape growing, mainly in the final stages of development of the annual growth cycle. The final phase that precedes harvesting is where climatic conditions play a critical role, making or losing the benefit of a whole year of work. Currently, growers use 4 to 5 days lead-time weather forecasts, together with sensory (tasting of berries) and physical-chemical parameters to select the date of harvest. They stressed the importance of accessing quality forecast services with greater temporal resolution, for decision making to be conducted in a timely manner, e.g., anticipating harvest upon the forecast of a rainy September. This prior knowledge would allow efficient and timely management of staff, both internal and subcontracted, and of wineries’ capacity to receive grapes. It would also allow for better negotiation of contracts, both of manpower and machinery, and guarantee the availability of required labour in the right moments.

The FG3 participants were asked what was the minimum forecast reliability that they would accept to take it into account in their decision-making. For activities inherent to this FG, seasonal forecasts are the ones that better fit most processes, the consensus reached was 70%, as established in FG2. Participants indicated that the best way to receive information from climate services would be via e-mail or SMS message, with ready-made information easy to interpret and understand.

“Prior knowledge of weather for the next months will allow for an advantageous contract negotiation for the company”

In FG4, the thematic was management of stocks of viticulture and oenological products needed to execute respective operations. Participants stressed the company's policy being zero stock - due to the standing investment and short-term validity of the products – and therefore all stated that having previous knowledge of weather conditions for the next months would be very advantageous from a financial perspective. It would allow them to negotiate contracts with suppliers in a timely manner, obtain better prices, representing a relevant economic footprint for the company, as well as avoiding moments of stress when the sudden acquisition of limited-availability products create stock breaks.

From the perspective of marketing and brand development within the company, this prior knowledge from seasonal forecasts, would be important to have to allow for analysing key moments for launching promotional or new brand campaigns and, consequentially, timely planning of the production of promotional materials.

As in the other groups, when asked about the minimum reliability that would trigger considering forecasts in decision-making, they all agreed that with 70% reliability they would use forecasts, and that it would be useful to obtain monthly temperature and precipitation data, updated every week with a 6-month lead-time.

The following flowchart (Figure 3) summarizes the results and outputs expected by participants in the four FGs from the MED-GOLD project.

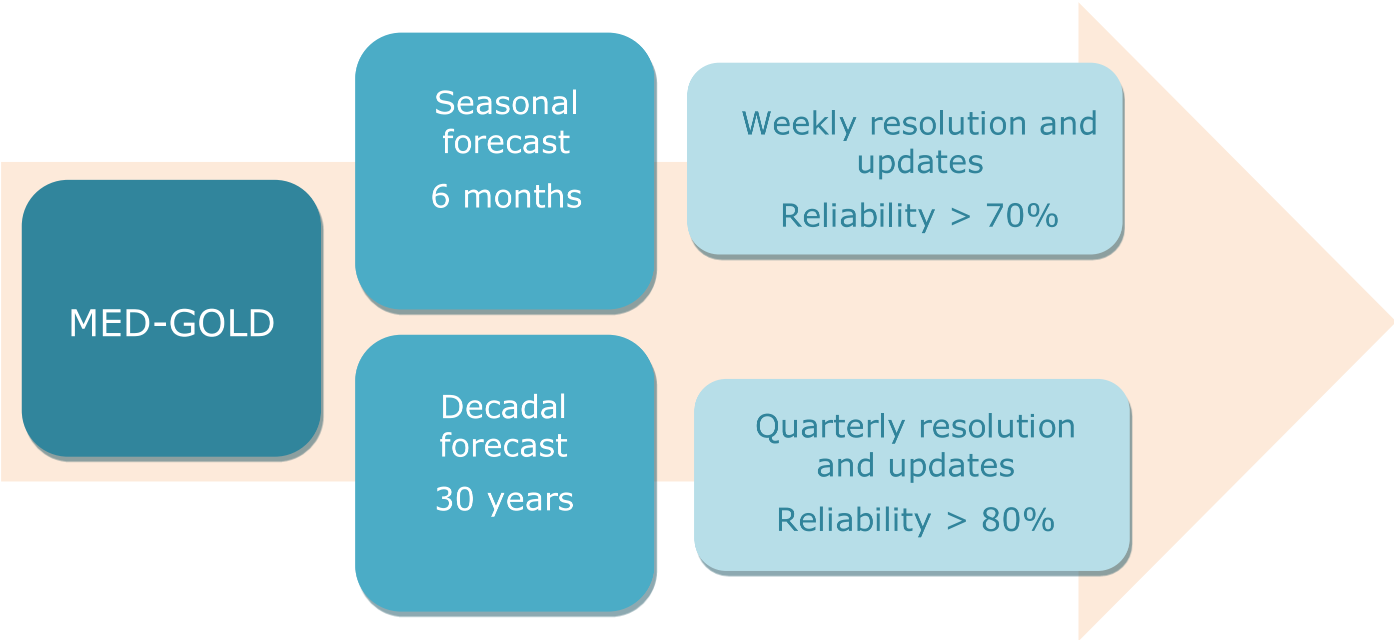

Figure 3 - Outputs expected by FG participants from the MED-GOLD project.

During the FG, some of the bioclimatic indices studied in Fontes et. al. (2016a) were introduced in the conversation. It became evident that because maximum daily temperatures above 35 °C (as reported by index SU35) stop sugar accumulation and decrease acidity in berries it may be an inhibitory element in the choice of a property for acquisition. The same may be said about the incidence of heat waves (as reported by index WSDI). The importance of early knowledge about spring precipitation involving application of plant protection products (as indicated by index SprR) was also evident.

The best way to obtain pilots from MED-GOLD was explored during the FG, trying to understand what type of variables / indices used by the project could generate value. The objective is to evaluate up to what extent timely forecasts of climate conditions would lead to different decision-making and simulating it against decisions made in the past.

For this to happen, the MED-GOLD team members within the company will work with their scientific counterparts to define which climate variables and indices best describe the interannual variability of quality and quantity of grape and wine production. A set of case-study years that typify the extreme variations of that production will also be identified.

5. CONCLUSIONS

"Há chuva que seca e sol que rega"

(There is drying rain and watering sunshine) - Portuguese proverb

Weather has different influences and, depending on the moment of the year, it may benefit or harm crops. MED-GOLD aims to predict these oscillations by taking advantage of these variations to drive value into farming of Mediterranean staple crops, among which are grapes and wine.

Focus Groups were held with the intention of understanding what information would be important to obtain in forecasts, seasonal and decadal, that could bring advantages to a wine company such as SOGRAPE.

With the focus groups it was possible to perceive among the target audience of MED-GOLD what their ambition for the project is and what they expect as a final product. In this way, it was possible to establish minimum thresholds of requirements in the use of MED-GOLD services noting that, depending on the decisions to be made, requirements vary with the level of impact of decisions on the company financials.

For seasonal forecasts, 6-month lead-time weekly forecasts of temperature and precipitation would be ideal, updated weekly, with a minimum reliability of 70%. It should be noted that one of the FGs mentioned they would like to have access to information, by e-mail or SMS, with ready-to-use information, easy to interpret and understand.

For decadal forecasts, quarterly projections of average temperatures (maximum and minimum) and precipitation would be ideal with quarterly updates. Additionally, it would be important to quantify the expected magnitude of increase / decrease of temperature. The agreed minimum reliability for which they would consider using such forecasts would be 80%.

6. BIBLIOGRAPHY

- Agnoletti, M., & Emanueli, F. (Eds.). (2016). *Biocultural diversity in Europe* (Vol. 5). New York: Springer.

- Alves, F., Almeida, F., Costa, J., Moutinho-Pereira, J., Aranha, J. (2006a). Water availability in hillside vineyards. Evaluation of grapevine water stress - Douro case study. Primo Congresso Internazionale sulla Vicoltura di Montagna e in Forte Pendenza - CERVIM - Saint Vincent d´Aosta - Italy, 17, 18 Mars, 2006;

- Alves, F, Almeida, F, Moutinho-Pereira, Magalhães N, Aranha J. (2006b). Monitoring water deficit in vineyards by means of infrared measurements. VIth International Terroir Congress Bordeaux;

- Bindi, M., Fibbi, L., Gozzini, B., Orlandini, S., & Miglietta, F. (1996). Modelling the impact of future climate scenarios on yield and yield variability of grapevine. *Climate research*, *7*(3), 213-224.

- Boyer, J. S., Wong, S. C., & Farquhar, G. D. (1997). CO2 and water vapor exchange across leaf cuticle (epidermis) at various water potentials. *Plant physiology*, *114*(1), 185-191.

- CEEV (2015). European Wine: a solid pillar of the European Union economy (https://bit.ly/2vxgqFI)

- Cola, G., Mariani, L., Salinari, F., Civardi, S., Bernizzoni, F., Gatti, M., & Poni, S. (2014). Description and testing of a weather-based model for predicting phenology, canopy development and source–sink balance in Vitis vinifera L. cv. Barbera. *Agricultural and Forest Meteorology*, *184*, 117-136.

- Cunha, M., & Richter, C. (2016). The impact of climate change on the winegrape vineyards of the Portuguese Douro region. *Climatic Change*, *138*(1-2), 239-251.

- Deschenes, O., & Kolstad, C. (2011). Economic impacts of climate change on California agriculture. *Climatic change*, *109*(1), 365-386.

- DR, 2012. Ministerial Order 380/2012, of 22 November, that establishes grapevine varieties fit and authorized for wine production in Portugal. Diário da República (Portugal), 1ª série – Nº 226, 22/11/2012.

- EUROSTAT (2011). Population by single year of age and NUTS 3 region [cens_11ag_r3]. Retrieved from http://ec.europa.eu/eurostat/data/database .

- EUROSTAT (2015). Causes of death - deaths by country of residence and occurrence [hlth_cd_aro]; Mental and behavioural disorders due to the use of alcohol. Retrieved from http://ec.europa.eu/eurostat/data/database .

- Fontes, N., Graça A.,(2013). A within-vineyard meteorological network: looking for vineyard-scale climate variability, 18th International Symposium GiESCO 2013, Porto, July 2013.

- Fontes, N., Martins J., Graça A.,(2015). Characterization of extreme climate events over four winegrowing regions in Portugal , 19èmes Journées GiESCO, Gruissan, May 2015.

- Fontes, N., Martins J., Graça A.,(2016a).High-resolution agrometeorological observations to assess impact on grape yield and harvest date , CLIMWINE 2016 - Sustainable grape and wine production in the context of climate change, Bordeaux, April 2016.

- Fontes, N., Martins J., Graça A.,(2016b). Study of agrometeorological measurements on “terroirs” of Alentejo wine region: impact on grape yield and harvest date variation, 10º Simpósio de Vitivinicultura do Alentejo, Évora, May 2016. Vol. 2

- Fraga, H., Malheiro, A. C., Moutinho-Pereira, J., Jones, G. V., Alves, F., Pinto, J. G., & Santos, J. A. (2014). Very high resolution bioclimatic zoning of Portuguese wine regions: present and future scenarios. *Regional environmental change*, *14*(1), 295-306.

- Fraga, H., Malheiro, A. C., Moutinho-Pereira, J., & Santos, J. A. (2014a). Climate factors driving wine production in the Portuguese Minho region. *Agricultural and Forest Meteorology*, *185*, 26-36.

- Fraga, H., Malheiro, A. C., Moutinho-Pereira, J., Jones, G. V., Alves, F., Pinto, J. G., & Santos, J. A. (2014b). Very high resolution bioclimatic zoning of Portuguese wine regions: present and future scenarios. *Regional environmental change*, *14*(1), 295-306.

- Fraga, H., Costa, R., Moutinho-Pereira, J., Correia, C. M., Dinis, L. T., Gonçalves, I., ... & Santos, J. A. (2015). Modeling phenology, water status, and yield components of three Portuguese grapevines using the STICS crop model. *American Journal of Enology and Viticulture*, ajev-2015.

- Graça A., Pessanha M., Porto J., Sottomayor L., Alves F., Costa J., Ojeda H. (2011). Control of vine water status: implementation of an irrigation strategy to increase the quality of grapes in a Touriga Nacional vineyard in the Douro Region, Portugal.Conference:9th International Symposium of Enology. Bordeaux. January 2011

- Guilpart, N., Metay, A., & Gary, C. (2014). Grapevine bud fertility and number of berries per bunch are determined by water and nitrogen stress around flowering in the previous year. *European Journal of Agronomy*, *54*, 9-20.

- Jones, G.V.(2005).Climate change in the western United States grape growing regions. Acta Horticultura e (ISHS), 689:41-60.

- Jones, G. V., Duchene, E., Tomasi, D., Yuste, J., Braslavska, O., Schultz, H., ... & Guimberteau, G. (2005a). Changes in European winegrape phenology and relationships with climate. In *XIV International GESCO Viticulture Congress, Geisenheim, Germany, 23-27 August, 2005* (pp. 54-61). Groupe d'Etude des Systemes de COnduite de la vigne (GESCO).

- Jones, G. V., White, M. A., Cooper, O. R., & Storchmann, K. (2005b). Climate change and global wine quality. *Climatic change*, *73*(3), 319-343.

- Jones G.V. (2007).Climate Changes and the global wine industry. 13th Australian wine industry technical Conference, Adelaide, Australia.

- Jones, G. V., & Alves, F. (2012). Impact of climate change on wine production: a global overview and regional assessment in the Douro Valley of Portugal. *International Journal of Global Warming*, *4*(3-4), 383-406.

- Jones, G. V. (2012). A climate assessment for the Douro wine region: an examination of the past, present, and future climate conditions for wine production. *collaboration with: ADVID the association for the development of viticulture in the Douro region Google Scholar*.

- Koufos, G., Mavromatis, T., Koundouras, S., Fyllas, N. M., & Jones, G. V. (2014). Viticulture–climate relationships in Greece: the impacts of recent climate trends on harvest date variation. *International Journal of Climatology*, *34*(5), 1445-1459.

- Magalhães, N.(2015). *Tratado de Viticultura*.2ªEdição. Esfera Poética.

- Malheiro, A., Ferreira, T., & Mathews, R. (2007, April). Transpiration of vineyards of Douro Region. In *Congreso Clima y Viticultura* (pp. 400-406).

- Malheiro, A. C., Santos, J. A., Fraga, H., & Pinto, J. G. (2010). Climate change scenarios applied to viticultural zoning in Europe. *Climate Research*, *43*(3), 163-177..

- May, P. (2004). *Flowering and fruitset in grapevines*. Phylloxera and Grape Industry Board of South Australia in association with Lythrum Press.

- Moriondo, M., Jones, G. V., Bois, B., Dibari, C., Ferrise, R., Trombi, G., & Bindi, M. (2013). Projected shifts of wine regions in response to climate change. *Climatic change*, *119*(3-4), 825-839.

- Nicholas, K. A., Matthews, M. A., Lobell, D. B., Willits, N. H., & Field, C. B. (2011). Effect of vineyard-scale climate variability on Pinot noir phenolic composition. *Agricultural and Forest Meteorology*, *151*(12), 1556-1567.

- OIV (2017). Statistical report on world vitiviniculture. OIV, Paris, France

- Ojeda, H., Sanchis, F. M., Corbacho, L., Bouquet, A., & Carbonneau, A. (2010). Reduction of costs and emissions in vineyards by the use of low-input technologies adapted to productions of good quality wines: genotypes resistant to fungal diseases and minimal pruning-zero pruning system. Progres Agricole et Viticole, 127(21/22), 431-440.

- Photiadou, C., Fontes, N., Graça, A. R., & van der Schrier, G. (2017). ECA&D and E-OBS: High-resolution datasets for monitoring climate change and effects on viticulture in Europe. In BIO Web of Conferences (Vol. 9, p. 01002). EDP Sciences.

- Ramos, M. C., & Martínez-Casasnovas, J. A. (2006). Impact of land levelling on soil moisture and runoff variability in vineyards under different rainfall distributions in a Mediterranean climate and its influence on crop productivity. *Journal of Hydrology*, *321*(1-4), 131-146.

- Ramos, M. C., Jones, G. V., & Martínez-Casasnovas, J. A. (2008). Structure and trends in climate parameters affecting winegrape production in northeast Spain. *Climate Research*, *38*(1), 1-15.

- Rosenzweig, C., Elliott, J., Deryng, D., Ruane, A. C., Müller, C., Arneth, A., & Neumann, K. (2014). Assessing agricultural risks of climate change in the 21st century in a global gridded crop model intercomparison. *Proceedings of the National Academy of Sciences*, *111*(9), 3268-3273.

- Taylor, J. A., Acevedo-Opazo, C., Ojeda, H., & Tisseyre, B. (2010). Identification and significance of sources of spatial variation in grapevine water status. *Australian Journal of Grape and Wine Research*, *16*(1), 218-226.

- Tomasi, D., Jones, G. V., Giust, M., Lovat, L., & Gaiotti, F. (2011). Grapevine phenology and climate change: relationships and trends in the Veneto Region of Italy for 1964–2009. *American Journal of Enology and Viticulture*, ajev-2011.

- Tonietto, J., & Carbonneau, A. (2004). A multicriteria climatic classification system for grape-growing regions worldwide. *Agricultural and Forest Meteorology*, *124*(1-2), 81-97.

- Urhausen, S., Brienen, S., Kapala, A., & Simmer, C. (2011). Climatic conditions and their impact on viticulture in the Upper Moselle region. *Climatic Change*, *109*(3-4), 349-373.

- Van Leeuwen, C., Friant, P., Chone, X., Tregoat, O., Koundouras, S., & Dubourdieu, D. (2004). Influence of climate, soil, and cultivar on terroir. *American Journal of Enology and Viticulture*, *55*(3), 207-217.

END OF DOCUMENT