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 1.2.

Assessing olive, grape, and durum wheat sectors' vulnerabilities, critical decisions and information needs

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	**Deliverable title**	
Brief Description	This report integrates findings from a systematic literature review, scoping workshops and focus group discussions on critical decisions related to climate change impacts, as well as climate information needs for olive, grape and durum wheat sectors.	
WP number	1	
Lead Beneficiary	*UNILEEDS*	
Contributors	*Elena Mihailescu* *Marta Bruno Soares*	
Creation Date	21/11/2018	
Version Number	1.1	
Version Date	26/01/2019	
Deliverable Due Date	31/12/2018	
Actual Delivery Date	31/01/2019	
Nature of the Deliverable	R	*R - Report* *P - Prototype* *D - Demonstrator* *O - Other*
Dissemination Level/ Audience	PU	*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	11-12-2018	UNIVLEEDS	67	Initial Draft
1.1.	26-01-2019	UNIVLEEDS	73 (without Annexes)	Revised version, integrating the feedback received from the partners and coordinators

Disclaimer

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With this deliverable, the project has contributed to the achievement of the following objectives (DOA, PartB Table1.1):

No.	Objective	Yes
1	To co-design, co-develop, test, and assess the added value of proof-of-concept climate services for olive-olive oil, grape-wine, and durum wheat-pasta sectors	X
2	To refine, validate, and upscale the three pilot services with the wider European and global user communities for olive-olive oil, grape-wine, and durum wheat-pasta	X
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	
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

EXECUTIVE SUMMARY

This report integrates findings from a systematic literature review, scoping workshops and focus group discussions on critical decisions related to climate change impacts, as well as climate information needs for olive, grape and durum wheat sectors. These integrated findings represent co-produced knowledge, as a starting point in the process of co-developing tailored climate services for end users operating in the three sectors and participating in MED-GOLD project.

Therefore, the scope of this report is multi-fold: (i) present specific decisions related to climate change impacts within specific agro-environmental contexts, as well as specific climate information needs identified through scoping workshops and focus group discussions; (ii) cross-validate the decisions identified through scoping workshops and focus group discussions, with the critical decisions related to climate change impacts identified through a systematic literature review at wider European level; (iii) identify decisions other than the ones identified through the scoping workshops and the focus group discussions. Further, the findings from the literature review can be also useful for task 6.2. by giving indications of potentially larger (if there are strong common findings across the different sources) or narrower applicability (if there are more different than common findings) to other European and, potentially, global crops (e.g. coffee) of the climate services to be developed within MED-GOLD.

The main integrated findings are summarized below.

Most commonly, the critical decisions across the olive, grape and durum wheat sectors, as indicated by the findings from the literature review, were related to the increase in temperature and occurrence of drought and water deficit and were related to management of crop genetic potential and water stress reducing measures (Table 9-1). Differently, the findings from the scoping workshops and focus group discussions indicated decisions most commonly affected by temperature, rainfall, air and soil humidity, and windiness, and were related to site choice and plantation design, pruning and training system, soil labouring, phytosanitary treatments, fertilization, yield estimation, and harvest timing and planning (Table 9-2).

These decisions are associated with impacts of climate change, such as generally reduced suitability of European cultivation areas, accelerated phenology leading to incomplete fruit maturation (olives, grapes) or grain filling (durum wheat), reduced and highly variable yield, increased incidence of pests and diseases (subject to favourable climatic

conditions), shifts in traditional varieties, altered bio-chemical fruit composition (olives and grapes), and shifted harvest dates, as indicated by the findings from the literature review.

However, for many of these climate change impacts there was also identified a positive side, albeit not for all the three sectors, and sometimes with tradeoffs, namely: a) a northward expansion of European grape cultivating areas, and olive growing areas – through shifting from other crops; b) a higher natural mortality of olive and grape pests under warmer and drier conditions but in parallel with the emergence of warm climate grapes' pests and diseases in northern European grape cultivating areas; c) a higher tolerance of red grape varieties to warmer and drier conditions at the same time with the lower resistance of the white grape cultivars; d) the opportunity for high quality wine production under warmer and drier conditions; e) an enhanced grapevine vigour under elevated CO_2 conditions; f) an increase in grape yields but only in the areas where an increase in temperature is coupled with an increase in summer rainfall; g) an increase in durum wheat cultivation areas but only when there is an increase in autumn rainfall; and i) an increase in durum wheat yield under elevated CO_2 conditions but only if there is no decrease in rainfall. Each of these positive impacts of climate change can represent opportunities to be identified and exploited by the olives, grapes and durum wheat producers, according to their specific needs. However, in this report, there were not identified any decisions associated with such positive impacts.

In terms of socio-economic decisions, they were both affected by climatic and economic drivers. The most common identified climatic drivers were the temperature, rainfall, and occurrence of drought and heat stress, which impacted on decisions relating to input purchase, use of modernization of machinery, labour management, stock management, harvest planning, crop insurance and supply chain contracting, at micro level. At macro level, the climatic drivers impacted on policy making related to economic growth and development of skills to quantify climate skills. As economic drivers, there were identified the consumer preferences and the availability of manpower at regional level, and the market price at macro level, and they acted in combination with the climatic drivers.

The most common identified climate information needs across the three sectors, relate to seasonal forecasts with different leading times, which have been found to be useful for short-term decisions (field activities, stock management) and to decadal forecasts – useful for medium- to long-term decisions (choice of sites and plantation design, choice of varieties, equipment purchase, monitoring of emergence of new pests, diseases, and invasive species of weeds).

1. INTRODUCTION

1.1. PURPOSE AND SCOPE

The Mediterranean region is considered as a hot spot for climate change, where cumulative and unevenly distributed impacts of these changes are increasingly severe (Grasso and Feola, 2012), with further negative implications for the productivity and viability of traditional crops, namely olives, grapes, and durum wheat. In this context, understanding the value and relative contribution of climate services may be critical for improving the adaptability of these cropping systems to climate variability and change (Vaughan and Dessai, 2014).

The MED-GOLD project aims to demonstrate a proof of concept for climate services and their added value for these three Mediterranean crops, by increasing the usability of climatic data and state-of-the-art seasonal forecasts and climate change projections with the contribution of world leading producers of the three representative Mediterranean food products: olive oil (DCOOP), wine (SOGRAPE), and pasta (BARILLA). These large producers, and, at the same time, end-users of climate information, will participate in the identification of necessary information and co-production of knowledge which can be used for the co-development of tailored climate services for the three Mediterranean crops and food products. The tailored climate services prototypes will be co-developed together with the scientific and private partners with climate and agriculture related working experience.

As a starting point for the process of co-developing the climate services prototypes, critical decisions affected by climate change impacts were appraised to help inform the knowledge base. In addition, the most pressing climate information needs to help inform decision-making processes in relation to olives, grapes, and durum wheat production activities were also examined through scoping workshops (olive and durum wheat sectors) and focus group discussions (grape sector), complemented by a systematic review carried out for validating and expanding the acquired knowledge.

Therefore, the scope of this report is multi-fold: (i) present specific decisions affected by climate change impacts within specific agro-environmental contexts, as well as specific climate information needs identified through scoping workshops and focus group discussions; (ii) cross-validate the decisions identified through scoping workshops and focus group discussions, with the critical decisions affected by climate change impacts identified through a systematic literature review at wider European level; (iii) identify decisions other than the ones identified through the scoping workshops and the focus group discussions. Further, the findings from the literature review can be also useful for task 6.2. by giving indications of potentially larger (if there are strong common findings across the different sources) or narrower applicability (if there are more different than common findings) to other European and, potentially, global crops (e.g. coffee) of the climate services to be developed within MED-GOLD.

1.2. DEFINITIONS AND ACRONYMS

1.2.1. Definitions

Concepts and terms used in this document and needing a definition are included in the following table:

Table 1-1 Definitions

Concept / Term	Definition
Vulnerability	Vulnerability has been defined as the propensity or predisposition of an individual, a community, assets or systems to be adversely affected by the impacts of hazards. It includes a variety of concepts and elements such as sensitivity or susceptibility to harm, and lack of capacity to cope and adapt. Vulnerability is a result of diverse historical, social, economic, political, cultural, institutional, natural resource, and environmental conditions and processes (EEA, 2017). In this report, vulnerability was examined in relation to how impacts of climate change can affect the olive, grape, and durum wheat sectors' activities and associated critical decisions at micro level in particular, and, to some extent, at macro level (context of economic and market conditions) (RD1)
Climate change impact	The term "impact" is used primarily to refer to the effects of extreme weather- and climate-related events, i.e. effects caused by the interaction of climate change or hazardous climate events occurring within a specific time period, and the vulnerability of an exposed society or system
Climate service	Timely production and delivery (translation and transfer) in customized products (projections, forecasts, information, trends, economic analysis, assessments, etc.) of useful climate-related data, information and knowledge that support adaptation, mitigation and disaster risk management to decision makers (RD2)

1.2.2. Acronyms

Acronyms used in this document and needing a definition are included in the following table:

Table 1-2 Acronyms

Acronym	Definition
MED-GOLD	The project entitled "Turning climate-related information into added value for traditional **MED**iterranean **G**rape, **OL**ive and **D**urum wheat food systems"
EEA	European Environment Agency
INRA	French National Institute for Agricultural Research

2. REFERENCES

2.1 Reference Documents

A comprehensive list of references can be found in Annex B.

3. METHODOLOGY

As a starting point to the process of co-developing the climate services prototypes, critical decisions affected by climate change impacts were appraised to help inform the knowledge base. In addition, the most pressing climate information needs to help inform decision-making processes in relation to olive, grape, and durum wheat production activities were also examined. For these purposes, there were conducted scoping workshops (olive and durum wheat sectors) and focus group discussions (grape sector), complemented by a systematic review for validating and expanding the acquired knowledge.

The methodology undertaken for each of these approaches is briefly described in the following paragraphs.

- **Scoping workshop for olive-olive oil sector**

For the olive-olive oil sector, MED-GOLD held a participatory workshop with the whole Field Technical Department of DCOOP, which is like a representation of the whole olive sector as DCOOP is the largest producer of olive oil and table olives in the world. The event was held on 12 June 2018 at the Assembly Hall of DCOOP´s offices in Antequera, Málaga. The workshop was an institutional and technical event attended by representatives from several institutions such as the Consejería de Agricultura Pesca y Desarrollo Rural (section of the Andalusian Government focusing in the agri-food sector), and some of the Spanish MED-GOLD project partners (GMV, BSC, ec2ce, and DCOOP). Round-table discussions were held to allow the participating organizations and the MED-GOLD project partners to understand the needs of the sector. Each organization participated in. Thirty people attended the workshop, including 19 agronomists who made up the Technical Field Department (TFD) from DCOOP, who were grouped in three tables as participants. The information collected was analyzed and will be used as a starting point for the development of climate services for farmers and agronomists. The methodology used to run this workshop is discussed in detail in section 3.1.1 of deliverable D 2.1 (RD3).

- **Focus group discussion for grapes-wine sector**

For the grapes-wine sector, there four focus group discussions were conducted on the 3rd and 4th of May at SOGRAPE's premises. As participants, key SOGRAPE staff linked to each thematic area were chosen with the objective of perceiving the influence that prior knowledge of climate information, both at seasonal and decadal scales, could have in their decision making. Owing to the diversity of activities within the company and the importance and influence of climatic conditions in SOGRAPE’s value chain, four distinct groups were selected for different thematic areas identified as critical for the company’s business: strategy, viticulture management, oenological management and stocks management. The methodology for this workshop is discussed in detail in section 3 of deliverable D 3.1 (RD4).

- **Scoping workshops for durum wheat-pasta sector**

For durum wheat-pasta sector, two workshops were held on the 15th and 16th May 2018 at the premises of Horta S.r.l. in Ravenna. The first workshop addressed Institution representatives, and the second focused on farmers and technicians.

In the first workshop, the 11 participants represented local political institutions, breeding companies, academia and stocks exchange markets. The aim of this first workshop was to ascertain the key operational and strategic decision-making processes that could potentially benefit from the use of seasonal climate forecasts, and long-term climate change projections.

In the second workshop, the 15 participants represented durum wheat farmers, producers’ associations and elevators (i.e. organisations that collect and store grains from several farmers, and sell the product to food industries), and technicians, all of them coming from different parts of Italy. Participants were selected among the users of Horta's Decision Support System (DSS) granoduro.net®, for the management of durum wheat crop that is presently used by Barilla's suppliers. In order to account for the geographical differences, participants were divided in 3 focus groups, based on their regional provenance.

The methodology for these workshops is discussed in detail in section 3.1 of deliverable D 4.1 (RD2).

- <u>**Systematic literature review**</u>

In addition to the scoping workshops and focus group discussions, a systematic literature review of academic publications and grey literature review was carried out to validate and provide additional knowledge on findings from the scoping workshops and focus group discussions.

The protocol followed for carrying out the systematic literature review includes the following stages: identification of the objectives; search eligibility criteria; search terms; search results screening; data abstraction, risk bias assessment; and data analysis, synthesis and presentation. These stages are described in detail in Annex A.

- ***Objectives of the review***

The objectives of this review were:

(1) To identify critical climate change impacts and vulnerability of decisions within and across olive-olive oil, grape-wine and durum wheat-pasta sectors in the most climate-sensitive European producing areas;

(2) To identify the socio-economic implications of climate change impacts on olive-olive oil, grape-wine and durum wheat-pasta sectors in these areas;

(3) To identify climate information needs of the olives, grapes and durum wheat producers operating in these areas.

- ***Search eligibility criteria***

The search eligibility criteria refer to: type of database (specialized, Google, CORDIS), language (English), timeframe (2000-2018), search fields, type of publications (academic and grey literature).

- ***Search terms and combination of terms***

The following combinations of search terms were used, to search for literature related to all the derivations of the truncated search terms. The derivations of the truncated words were checked with CAB Thesaurus (Anonymous, 2018*a*).

climat*

AND one of the following: **grape** / **vine** / **durum wheat** / **oliv***

AND

Europ*

By using "AND" Boolean operator, we narrowed down the search, as this operator requires to be included at least one search term from the lists given on each side of the operator (Anonymous, 2018*b*).

The initial search retrieved a number of 1747 peer-reviewed and grey documents.

- ***Search results screening***

After the search was finalised, the titles, abstracts and keywords of the articles identified were screened according to the eligibility criteria (Bernes *et al.,* 2018).

There were retained 68 results, including peer-reviewed and grey literature, for the data abstraction phase.

- ***Data abstraction***

After screening and study identification, key data (see Table 2 in Annex A) were abstracted into data abstraction forms. These forms were centralized in one single centralized Excel form including the data for all the abstracted studies. The data abstraction form used for this purpose is included in Annex A.

The centralized data abstraction form documented general and specific information (Annex A,Table 2) to be further used in data analyses (Söderström *et al*., 2014).

- ***Risk bias assessment***

We performed a critical assessment of study quality, through a combination of identified factors that may bias the review output.

For this systematic review, we took into consideration the following types of biases:

- Biases (systematic errors) in the search strategy, which may affect the search outcomes operator (Anonymous, 2018*b*);
- Possible publication bias, where 'positive' (i.e. confirmative, statistically significant) results are more likely to be published in academic journals rather than in grey literature operator (Anonymous, 2018*b*);
- Confounding during data abstraction process **(**Viswanathan *et al.,* 2012; Li *et al*., 2015)

We attempted to minimize confounding by identification of potential factors which might be potential confounding variables or effect modifiers (i.e., correlated with other factors) (Singh, 2017; Bernes *et al.,* 2018)

- ***Data synthesis and analysis***

The identified climate change impacts and critical decisions for the three crops (olive tree, grapevine, and durum wheat) and associated products (olive oil, wine, and pasta) were encoded as nodes in NVIVO and grouped into specific types and sub-types, by running several queries. The encoded findings, grouped as detailed in section G of Annex A, are presented in tables for each of the three crops.

NVIVO is a qualitative data analysis computer software package produced by QSR International. It has been designed for qualitative researchers working with very rich text-based and/or multimedia information, where deep levels of analysis on small or large volumes of data are required.

Cluster analysis, defined as a multivariate method which aims to classify a sample of subjects (or objects) on the basis of a set of measured variables into a number of different groups such that similar subjects are placed in the same group, was performed for the nodes created in NVIVO, to:

- Identify common climate change impacts and related decisions across the three crops;
- Verify the relationships between climate change impacts and related decisions for the three crops.

The values of Pearson coefficient were calculated in NVIVO to measure the linear correlation for each pair of climate change and related decision.

The statistical significance was verified by deriving P-values for the investigated correlations and the calculated Pearson coefficients by using the P Value from Pearson Calculator for social science statistics (Anonymous, 2019).

4. TRENDS AND REGIONAL DISPARITIES IN CLIMATE VARIABILITY AND CHANGE AT EUROPEAN LEVEL

The impacts of climate change are intrinsically difficult to understand because changes in physical and social variables often occur at very different geographical and time scales (Iglesias *et al.,* 2012). These impacts are particularly severe for the agricultural sector (Giannakis and Bruggeman, 2015), mainly due to the dependence of agricultural practices, water use and production and quality of crops on local climate variables and levels of atmospheric carbon dioxide (CO_2) (Ciscar *et al*., 2011; Lorencová *et al.*, 2013).

The distribution of the climate change impacts on the agricultural sector has been reported to be uneven across regions, countries, and areas within countries. Their severity depends on local physical and environmental conditions, as well as on the adaptive capacity of the different natural and social systems (Urrestarazu *et al.*, 2010; Grasso and Feola 2012).

However, among the European agricultural regions, hot spots have been identified where most climate change and related impacts have been and will be expected to be more manifest. Areas within Europe include the Mediterranean, southern and central areas (Dubrovsky *et al*., 2014). The economically important crops in most of the southern areas, and particularly in the Mediterranean region, where they are also considered traditional, are: **olives** (*Olea europaea*), **durum wheat** (*Triticum durum*), and **grapes** *(Vitis vinifera)* (Ponti *et al*., 2018). Detailed examples of climate change effects on these three crops are discussed in sections 5.1.1 (olive), 6.1.1 (grape) and 7.1.1 (durum wheat).

The climatic changes relating to temperature, rainfall, atmospheric carbon dioxide, as well as occurrence of extreme events have been identified as having the largest impacts on crop development, production and quality, as well as on agricultural practices and management. Each of these change is detailed in the following sections.

4.1. Temperature

It has been argued that the main measurable effect of climate change is a steady increase in temperature (van Leeuwen and Darriet, 2016). Despite the general upward trend in temperature, European agriculture will experience different impacts across regions and geographical areas.

Temperature is expected to increase all over Europe during the 21st century, mainly during the winter months in eastern areas, but most of all during the summer months in south-western areas, by up to between 2.2°C and 5.1°C (Malheiro *et al.,* 2010; Salazar-Parra *et al.*, 2018).

For the central and eastern areas of Europe, an increased variation of annual temperatures is estimated (Vršič and Vodovnik, 2012; Dubrovsky *et al.,* 2014). More precisely, increases in temperature between 0.5 to 2.5°C are expected to occur by 2030 in eastern Europe (Vršič and Vodovnik, 2012).

These changes in annual temperatures will impact in terms of lower harvestable yields, higher yield variability and a reduction in suitable areas for traditional crops, predominantly in the southern areas (reviewed in Bindi and Olesen, 2011), and, to different extents, in eastern and central areas.

By comparison, in the northern regions of Europe, the projected increases in temperature are expected to be higher during winter and spring months, leading to potential positive impacts on crops, such as longer growing seasons, earlier sowing (Peltonen-Sainio *et al.*, 2016), northward expansion of suitable cropping areas, a reduction of the growing period (Lorencová *et al.*, 2013), and increases in productivity and a wider range of cultivated species (reviewed in Bindi and Olesen, 2011).

In this light, the northern agricultural regions in Europe could potentially benefit over the southern regions in terms of the impacts of changing temperatures on crop production (all other factors being equal).

4. 2. Rainfall

If a steady increase in temperature is acknowledged as a measurable effect of climate change, there is less consensus exists concerning a modification in rainfall patterns. This may be because rainfall is a discontinuous phenomenon, and tendencies can be assessed only over very long periods (several decades). Moreover, it is likely that modifications in rainfall will differ from one region to another (van Leeuwen and Darriet, 2016).

Nevertheless, in the context of predicted reduction in available water resources and changes in crop water requirements (Urrestarazu, *et al.*, 2010), in parallel with reported and predicted increase of agricultural water use across Europe (Heumesser *et al.*, 2012), the observed and predicted changes in annual amounts and distribution of rainfall across European agricultural regions is of greatest importance.

In terms of the predicted annual mean rainfall, a large north–south precipitation change gradient is expected (Mechler *et al*., 2010), with increases in most of the northern European regions and decreases of up to 27% in most of the southern regions (Malheiro *et al.*, 2010). For central Europe, the precipitation rates are projected to decline during summer but increase during winter months (Heumesser *et al*., 2012).

The predicted increases in mean annual rainfall amounts may be beneficial for most of the northern European regions in comparison with southern and central regions. However, the annual rainfall distribution pattern in northern Europe seems to be much less beneficial. The increases in rainfall amounts are projected to be the greatest in the winter months, with slight increases during the growing season, in spring and autumn. However, the predicted increased rainfall amounts are expected to be unevenly distributed during spring and autumn (Peltonen-Sainio *et al.*, 2016).

Such a rainfall pattern may be expected to be of little benefit to crops grown in northern and central European agricultural regions, in which crops often require evenly distributed rainfall for optimal growth. In addition, the slight increases in rainfall amounts during growing season are unlikely to meet crop water requirements during expected warmer and longer growing seasons (see section 4.1.), resulting in potentially lower attained yields (Peltonen-Sainio *et al.*, 2016).

In this context, there seem to be no real benefit in relation to the expected changes in rainfall across Europe, as the changes in the distribution pattern in the northern Europe counters the increases in rainfall amounts.

4.3. Atmospheric carbon dioxide

In this section, the main focus is on changes in atmospheric CO_2 concentration. Changes in tropospheric ozone (O_3) concentrations are also briefly discussed, as they have the potential to reduce any positive impacts of changes in CO_2 concentration.

It has been acknowledged that tropospheric CO_2 concentration has been increasing and is expected to further increase up to 50 per cent of pre-industrial levels by 2050. In industrialized countries of the Northern Hemisphere, tropospheric O_3 has also been rising by 1–2 per cent per year since the 1970s (reviewed in Long *et al.*, 2005).

However, the opinions on general effects of increased CO_2 concentration on crops are divided. Some of them refer to stimulation of yield by decreasing photorespiration while increasing the use of greater carbon gains in C3 crops, such as wheat (which use a different photosynthetic pathway to C4 crops) and transpiration in all crops (C3 and C4) (reviewed in Long *et al.*, 2005). Other studies refer to potential yield increases for only some crops, including wheat, but also to the alteration of their nutritional quality and of the range of crops grown under increased CO_2 concentration conditions (reviewed in Rounsevell and Reay, 2009). Such opinions should be considered while being aware that CO_2 effects vary considerably across crops and production conditions (Iglesias *et al.*, 2010) and can be reduced by, for example, decreased precipitation during summer and increasing variability of annual precipitation in agricultural regions

(Aurbacher *et al.*, 2013). Additionally, it has been reported that elevated atmospheric O_3 concentrations have been contributing to lower crop yields through decreased photosynthetic rate, accelerated leaf senescence and decrease ovule fertilization (reviewed in Long *et al.*, 2005). Therefore, increased tropospheric O_3 concentrations may cancel the more positive effects of a higher atmospheric CO_2 concentration.
The opinions on region specific impacts of increased CO_2 concentration on crops are more uniform. Some argue that predicted enhanced CO_2 atmospheric concentration will vary uniformly over the Earth's surface and therefore it will not be associated with differentiated impacts across the different agricultural European regions (Malheiro *et al*., 2010). Similarly, others refer to modest overall impacts of increased CO_2 concentration on crop yields regardless the dryer conditions in the southern European regions or the wetter conditions in the northern regions (Audsley *et al.*, 2015).

In a nutshell, the impacts of the changes in atmospheric CO_2 concentrations tend to be more positive, up to certain levels, even though largely uncertain, than the ones of the changes in temperature (section 4.1.) and in rainfall (section 4.2.) but may be diminished by the latter and by the changes in tropospheric O_3 concentration, and may vary more across types of crops and crop production practices rather than across spatial scales.

4.4. Extreme weather events

It has been argued that European agriculture will be most affected by the increase in frequency and severity of extreme weather events (Giannakis and Bruggeman, 2015) of which droughts have been identified as most damaging due to their associated long-lasting environmental, economic and social impacts (Carrão *et al.*, 2016).

The calculated drought severity indicates different trends across European regions, with significant increases in parts of the Mediterranean region (Iberian Peninsula, France, Italy and Albania), as well as in parts of south-eastern Europe and central Europe. Conversely, drought severity has decreased in northern Europe and parts of eastern Europe (Heumesser *et al.,* 2012; EEA, 2017). Among these regions, extreme hot and dry summers (similar to 2003) are likely to become common in Southern Europe (Salazar-Parra *et al.*, 2018). Even in some humid areas, such as Northwest France and Southeast England, a moderate to severe drought hazard has been reported (EEA, 2017).

The main impact related to the increased drought hazard is the risk posed to crop production and, implicitly, to food security particularly in the longer term (Carrão *et al.*, 2016), with southern Europe being particularly sensitive (Mechler, *et al.*, 2010).

The occurrence, and related impacts, of other extreme events are further discussed for the Mediterranean region, in section 5.5.

5. SPECIFICITIES OF CLIMATE CHANGE IN THE MEDITERRANEAN AREA

The Mediterranean region is considered as a hot spot for climate change, where cumulative and unevenly distributed impacts of such changes are increasingly severe. These include: increased frequency of extreme meteorological events, increased inter-annual climatic variability, reduction of suitable areas for traditional crops, sea level rise, increased soil salinity, and coastal erosion (Grasso and Feola, 2012). Among these, a particularly severe impact is the increase in water stress due to increasingly frequent water shortages (Dubrovsky *et al.,* 2014; Københavns Universitet, 2013). Additionally, a temperature increase of 1.5°C in the last 100 years, and up to 2°C expected in the coming years, coupled with: a) predominantly negative trend in precipitation in the last 50 years across the region; b) a decrease and variability in the coming years, and c) limited ground water resources, have a direct impact on the occurrence of more frequent and more severe droughts and overall accelerated drier conditions (Ponti *et al.*, 2014; Dubrovsky *et al.*, 2014; Mereu *et al.,* 2016; EEA, 2017).

The severity and uneven distribution of these cumulative impacts indicate that agriculture in the Mediterranean region is particularly sensitive. A substantially uneven reduction in agricultural production is expected, particularly in the southern areas (Grasso and Feola, 2012).

6. VULNERABILITY OF *OLIVE - OLIVE OIL* SECTOR TO CLIMATE VARIABILITY AND CHANGE

6.1. Findings from the literature review

In this chapter, as well as in sections 7.1 and 8.1, the most common identified climatic changes and related negative and positive impacts on olive crops are presented, as well as the farming decisions affected by these impacts.

Noteworthy, all the tables in this section are presented with alternative shaded and blank areas, to enhance horizontal visualisation for similar types of climate change impacts and decisions.

6.1.1. Climate change impacts, and critical decisions, on European Oliviculture

The most common identified impacts were on olive cultivation areas, olive tree development and phenology, yield, and pests and diseases.

6.1.1.1. Cultivation areas

The identified climate change impacts on olive tree cultivation areas were mostly related to changes in temperature, rainfall, and windiness (Table 6-1) and are further discussed, where possible, together with associated identified olive farmers' decisions.

Table 6-1: Climate change impacts on olive tree cultivation areas and critical decisions

Expected change	***Impacts***	**Critical decisions**
Decrease in temperature below the minimum requirements of olive trees	***Reduction of cultivation areas***	***Settling olive orchards on hill slopes***
Increase in temperature above maximum supported by olive trees		***Irrigation***
Decrease in rainfall below minimum requirements of olive trees		
Variation in weather variables	***Desertification***	
Risk of late spring/ early autumn frost	***Lowered suitability of cultivation areas***	***Choice of areas near water masses***
Severe windiness		
Decrease in rainfall below minimum requirements of olive trees + economic drivers	***Expansion of cultivation areas***	***Policy making to support economic growth***
		Shift in crops

Ideally, the olive tree cultivation areas are located in regions with a lowest annual temperature between 6/7°C and 8.3 °C, minimum annual rainfall amount between 350 and 400 mm (Tombesi *et al*., 2007; Ponti *et al.*, 2014), no, or very low risk, of late spring (April-May) and/or early (autumn) frosts (no more than one frost every 10-15 years), and light winds. Therefore, for example, the Turkish olive farmers from Çanakkale Province, a main olive producing area, decided to avoid Can and Yenice districts, and settle their orchards in areas bordering the Aegean Sea, which are protected from cold northerly winds (Kaleci and Gündoğdu, 2016).

Less common, olive tree cultivation can be carried out even in areas strongly affected by ***desertification,*** a consequence of, among other factors, climatic variations and human activity. One example is the region of Calabria (Southern Italy), where, additionally, the olive trees' deep roots play a major role in preventing soil erosion. However, in these areas, the olive farmers decided to ***ensure proper irrigation conditions*** of olive trees (Coscarelli *et al*., 2016).

The climatic suitability of olive tree cultivation varies across regions. More precisely, the northern cultivation areas are characterized by mild winters, with ***temperature often falling below zero***, and ***hot, dry summers***. In these areas, the olive farmers are generally advised to ***plant the olive groves on hill slopes***, at intermediate altitudes, where the temperature meets the olive tree requirements. By comparison, the southern cultivation areas must meet the chilling requirement of less than 11-12^{0}C for at least one month, to ensure an optimum rate of breaking the bud dormancy breaking (Tombesi *et al.*, 2007).

Changes to the optimum values of weather variables can considerably lower the suitability of existing olive tree cultivation areas. More specifically, in the southern Mediterranean rain-fed areas, the olive tree cultivation has been experiencing critical water shortages (Quiroga and Suárez, 2016) owing to increased droughts from the effect of changes in temperature and rainfall patterns, as discussed in section 5. Under such conditions, the ***cultivated areas are expected to shrin***k if olive farmers cannot adequately ***irrigate*** their crops.

However, there have also been reported expansions of cultivated areas, but only when coupled with economic interests. More precisely, in Fuente Palmera district, located in Cordoba, southern Spain, with predicted increase of up to 20 % in crop water requirements by 2050 due to climate change, the olive tree cultivation areas were monitored over a decade under the conditions of two different scenarios: one more driven by ***policy making for boosting national economic growth*** and one more oriented towards policy making to support regional economic, social, and environmental sustainability. The cultivation areas maintained an increasing trend more under the first than under the second scenario (Urrestarazu *et al.*, 2010). In another part of Spain, there was reported a conversion of cultivation area due to ***decreased water availability coupled with*** another ***economic driver***. More precisely, in a part of north-eastern Andalusia, farmers ***converted their rainfed cereal crops into irrigated olive groves***, owing to a decrease in annual rainfall and a drop in cereal market prices (Ronchail *et al*., 2014).

6.1.1.2. Olive tree development and phenology

The identified climate change impacts on olive tree development and phenology were mostly related to changes in temperature, and to a lesser extent to changes in rainfall, windiness, hailstorms and snowfall (Table 6-2), and are further discussed, where possible, together with associated identified decisions of olive farmers.

Table 6-2: Climate change impacts on olive tree development and critical decisions

Expected climate change	***Impacts***	***Critical decisions***
Decreases in temperature below minimum requirements of olive trees	***Impeded leaves' development***	***Settling olive orchards near large masses of water***
Frequent lower than optimum temperatures at planting time	***Damage of whole aerial part of the olive grove***	***Rescheduled planting date (in cold environments)*** ***Planting during winter (in hot environments)***
Risk of late autumn frosts	***Irreversible damage of the non-harvested fruits***	***Earlier harvest date***
Prolonged increases of temperature above the maximum supported by olive trees	***Limited vegetative activity***	***Adjusted shape of olive tree***
Increases in temperature during fruit ripening	***Reduced olive oil's resistance to oxidation***	***Harvest at fruit removal force < 3-3.5***
Prolonged and/or repeated water stress	***Reduced olive oil quality***	***Water stress reducing measures***
Uneven distribution and reduced amount of rainfall during fruit setting and development stages	***Limited fruit development***	- ***Irrigation during the vegetative period (annual rainfall > 700 mm);*** - ***Irrigation during vegetative and productive period (annual rainfall 500 - 700 mm);*** - ***Irrigation + additional water stress reducing measures (annual rainfall 400 - 500 mm)***
Severe windiness	***Breaking of shoots and branches, dropping of flowers and fruits***	***Use of living windbreaks or mechanical barriers***
Increases in hail amount and frequency	***Damaging of the inflorescences shoots, branches and fruits, increased risk of diseases***	***Pathogen treatments***
Increases in snowfall	***Breaking of branches***	-

The changes in temperature towards decreases and increases below and above supported thresholds were reported as damaging the olive tree development and causing changes in their phenology. More specifically, temperatures as low as -6/-7^{0}C, occurring for several days in the row, were found to substantially affect the leaves' development, while the fruits, usually richer in unsaturated fatty acids than in warmer environments, are more resistant to such temperatures and, additionally, have higher content of oleic acid and phenols conferring added quality to the oil (Tombesi *et al*., 2007; Proietti and Regni, 2018). Therefore, such temperatures have ***negative effects on leaf development*** and rather positive effect on olive fruit composition, and, further, on olive oil quality. In such areas, for the purpose of thermal mitigation, olive farmers are advised to ***settle the olive orchards near large masses of water***, such as lakes and seas (Proietti and Regni, 2018), even though in marine areas there is high probability of damage from salt transported by marine winds, as discussed later in this section.

Temperatures below -14/ -15°C, if occurring at planting time and more than once in 10 years, and even for a limited period of time, have the potential to seriously ***damage the whole aerial part of the olive grove***, in colder environments. In such events, olive farmers are advised to ***reschedule the planting date*** accordingly. Conversely, in hot and/or arid environments, where the main problem is spring/summer aridity, olive farmers are advised to ***carry out planting during the winter*** (Proietti and Regni, 2018).

Autumn frosts (where temperatures fall to -3/-4 °C) can ***irreversibly damage the non-harvested moisture-rich fruits*** (Tombesi *et al.,* 2007). Therefore, in such areas, olive framers are advised to ***complete harvesting 1-2 weeks earlier***, to minimize fruit frost damage, which could cause a reduction of olive oil quality in the form of a serious sensorial defect, known as "freezed" effect (Proietti and Regni, 2018).

In the events of changes in the minimum required temperatures during the chilling period, olive farmers need to be aware that such increases may alter the duration of dormancy required by olive trees, and, consequently, the yields (Ronchail *et al*., 2014).

On the other hand, prolonged increases of days with temperatures above 40-45°C, especially if associated with low water availability, can negatively impact the olive tree development, by ***limiting the vegetative activity***, owing to a reduction of foliar transpiration occurring as an adaptation mechanism to dry conditions. However, such adaptation, involving self-activation of biological mechanisms, such as the closure of the stomata, the reduction of transpiration and photosynthesis, the modulation of root growth and aerial vegetation and osmotic adjustment, enable the olive trees' ability to survive under severe water stress conditions, unlike other temperate species. In such environments, olive farmers are advised to ***adopt tree shapes (e.g. globe***) that may help avoiding exposure of the branches to direct sunlight, to avoid harmful scorching of the wood (Proietti and Regni, 2018).

If these sudden increases in temperature occur during fruit ripening, the linoleic acid content of the oil is increased in parallel with a sudden drop in its oleic acid content, i.e. the ***alteration*** of the ratio of monounsaturated to polyunsaturated fatty acids, and, therefore, ***of olive oil's resistance to oxidation***. To prevent this to happen, olive farmers can decide to start harvesting as soon as 10-20% of the olive fruits have a value of ***fruit removal force less than 3–3.5*** (Tombesi *et al.*, 2007).

The changes in the rainfall amount mainly impact on olive tree development, in terms of canopy volume, which can increase up to 13,000 m^3 ha^{-1} at an annual rainfall above 850 mm and decrease with decreasing rainfall amount (Tombesi *et al.*, 2007). Nevertheless, under rain fed conditions, the amount and distribution of rainfall during the fruit setting stage is critical, as the ***fruits have lower force than leaves in attracting the water available in the plant, which can limit their optimum development***. Besides fruit growth, the onset of a sensorial defect in the oil ("dry-wood") can be induced during fruit ripening and oil synthesis, in the event of prolonged and/or repeated water stress. Therefore, under dry olive farming (i.e., non-irrigated), the olive farmers are advise to make their decisions in accordance with the amount of rainfall, from ***irrigation during the vegetative period (for an annual rainfall above 700 mm), and during vegetative and productive period (for an annual rainfall between 500 and 700 mm), to irrigation combined with additional water stress reducing measures, such as careful control of weeds, low plant density, adequate intensity of pruning*** (for an annual rainfall below 400-500 mm) (Proietti and Regni, 2018).

A possible more important impact identified for olive tree development is severe windiness, which can cause ***breaking of shoots and branches, dropping of flowers and fruits***, caustic action on leaves and shoots (if, additionally, transporting salt, from marine areas), interfere with plant disease and herbicide treatments (drift effect). Therefore, olive farmers are advised to ***use living windbreaks (by growing cypresses, eucalyptus, etc.), or mechanical barriers*** constituted by robust nets anchored to iron, wood or concrete piles. If such severe winds are also hot, they can cause burns in apical leaves and damage flowers and fruits, whereas if they are cold, they can cause sudden drops in temperature (Proietti and Regni, 2018), with negative effects on the general olive tree development.

Increases in frequency and amounts of hailstones causes the most damage during the phases of flowering and fruit growing and ripening, through ***breaking of the inflorescences and the shoots, injuring of the branches and the***

fruits. Indirect damage can occur through the wood wounds which favour the penetration of bacterial infections, such as the olive knot disease. Therefore, immediately after a hailstorm, olive farmers are advised to ***apply pathogen treatments*** against this disease (Proietti and Regni, 2018).

Increases in snowfall may have negative effects mostly on next year's yield through ***breaking of olive tree branches*** (Kaleci and Gündoğdu, 2016).

The results of the cluster analysis indicated rather low values (between 0.08 and 0.14) and not statistically significant (average *P*-value 0.91) of the Pearson coefficient for the analysed correlations between the identified climate change impacts and associated critical decisions. The most relevant correlations identified were:

(a) between the impacts of increases in temperature above the maximum growing temperatures by olive trees and the decision to irrigate during the vegetative and productive stages (Pearson coefficient 0.14);
(b) between impacts of rainfall distribution during fruit setting and development stage under rain fed conditions and the decision to irrigate during the productive period (Pearson coefficient 0.12);
(c) between impacts of rainfall amount on olive tree canopy and the decision to irrigate during the vegetative phase (Pearson coefficient 0.09).

On one hand, these correlations underline the importance of changes in temperature and rainfall amounts and distribution for the optimum development of olive trees. On the other hand, they indicate that the main decision affected by these changes is irrigation, which may bring the question of the possibility to ensure optimum irrigation conditions for olive groves under the various environmental conditions in which they are being cultivated. However, the low values of the Pearson coefficients might indicate that there are other more important factors (e.g., olive plantation design and installation, cultivar section, pruning and training, fertilization, soil management, management of weeds, diseases and pests) impacting on olive trees development.

6.1.1.3. Olive yields

To avoid any confusion, it is important to make clear that in the reviewed literature the olive yield is commonly expressed as olive fruit weight per hectare.

The identified climate change impacts on olive yields were mostly related to changes in temperature and rainfall (Table 6-3), and are further discussed, where possible, together with associated identified decisions of olive farmers.

Table 6-3: Climate change impacts on olive yield and critical decisions

Expected climate change	*Impacts*	Critical decisions
Increase in summer temperature	***Decrease in yields***	- ***Water stress reducing measures;*** - ***Management of crop genetic factors and of soil conditions***
Uneven increase in temperature across regions	***Highly variable yields***	- ***Abandon of farms at risk (where increased pest infestation is expected);*** - ***Irrigation + development of skills to quantify climate risks;*** - ***Management of crop genetic factors and of soil conditions;*** - ***Adjusted agronomic practices ;*** - ***Decisions based on information on local disparities***
Decreases in rainfall in spring and summer	***Decrease in yields***	- ***Water stress reducing measures;*** - ***Management of crop genetic factors and of soil conditions***

The projected increases in maximum summer temperatures in Europe (above 40^{0}C) is expected to severely alter the agricultural yields of olives, particularly towards the end of 21st century. The sensitivity of olive yields to impacts associated with increased maximum temperatures, such as drier conditions, has been questioned. Ronchail *et al.* (2014) discussed contradictory views indicating, on one hand, the acknowledged resistance of olive trees to drought, and therefore, rather low sensitivity of yield to increased summer temperatures. On the other hand, previous findings about negative relations between olive yields and transpiration, indicate a rather high sensitivity of yields to increased summer temperature***.*** In section 6.1.1.2, it has been identified a limited vegetative activity as adaptation of olive trees to dry conditions, which corroborates with the views on ***olive yield sensitivity to increased summer temperature***, to the extent that, in such event, without irrigation, which may re-enable most of the normal biological activity, and therefore normal olive tree performance, the olive yields are very likely to be affected as well. However, other authors noted that some limitations, such as the ones imposed by increased respiration due to increased temperature, would not be removed by irrigation (Ponti *et al.,* 2014), not to mention that a higher evapotranspiration rate implies a substantial increase in the amount of water needed for irrigation (Iglesias *et al*., 2010). Therefore, there might be needed additional ***water stress reducing measures***, such as the ones discussed in section 6.1.1.2.

In the Mediterranean Basin, one important hotspot for unevenly distributed increases in temperature and drought occurrence across areas (section 5), and, at the same time, the region supplying 97% of the world's olives, there is, however, a predicted 4.1% increase in total yield and a decrease in yield variability by 2050 (Ponti *et al.,* 2014). Nevertheless, at local scale, olive tree varieties, age structure, agronomic practices, and occurrence of pest and diseases across the basin are important factors to consider as affecting amounts and ***variability of olive yields***. As such, across the European areas of the Mediterranean Basin, the olive yield is predicted to increase in parts of Italy (from 2.14 to 2.37 t ha^{-1}), but with lower oil quality, as well as in northern Portugal and central Spain (from 1.51 to 1.71 t ha^{-1}). In parts of France, the yield could increase from 2.14 to 2.37 t ha^{-1}, but with higher pest infestation, while yields are expected to decrease across the Middle East. In the areas where substantial economic losses exacerbated by increased pest infestations are expected to occur, such as in some marginal areas affected by desertification in Greece and Italy, olive farmers are likely to ***abandon the smallest farms at risk*** (Ponti *et al.*, 2014). In parts of Spain with a southern Mediterranean coastal climatic conditions, where olive production has been found to be at risk without irrigation, there are recommendations for ***development of skills to quantify climate risks*** associated with specific geographical locations for olive crop (Iglesias *et al.*, 2010).

Rainfall occurrence during spring and summer is another factor impacting on olive fruit yield, as the highest water requirements of olive trees are during the flowering and fruit production periods. In areas such as Andalusia, which is one of the world's leading olive producing regions, rainfall is predicted to decrease by 20% to 30%. ***The yields,*** especially for rainfed olive groves, are ***projected to decline*** by the middle of the century or sooner and continue to decline further by the end of the century (Ronchail *et al.,* 2014), and the olive farmers are expected to apply proper ***water stress reducing strategies***.

In this context of high variability of impacts of changes in temperature and rainfall across olive producing regions, the level of adaptation so far as to maintain or, ideally, to increase the olive yields, requires consistent information on ***regional and local disparities*** of their emergence (Iglesias *et al.*, 2010). Such information can help olive farmers to ***make informed decisions*** towards either adapting to these impacts (in areas where olive yields are expected to decline) or to maximize the opportunities (in the areas where the olive yields are expected to increase).

A decision more general but suitable to all of the above climate change impacts can be the ***management of crop genetic factors and of soil conditions,*** which may contribute to increasing olive orchard productivity. It has been acknowledged that one of the requirements for obtaining increases in olive yields is to grow the best varieties in areas best suited to olive growing (Tombesi *et al.*, 2007).

6.1.1.4. Olive pests and diseases

The identified impacts of climate change on olive tree diseases and pests were mostly related to changes in temperature and rainfall, and occurrence of spring frosts and hailstorms (Table 6-4) and are further discussed, where possible, together with associated identified decisions of olive farmers.

Table 6-4 Climate change impacts on olive pests and diseases and critical decisions

Expected climate change	*Impacts*	*Critical decisions*
Increases in maximum daily temperature + drier conditions	***- High natural mortality of pests (all stages)***	-
Increases in temperature during late spring /summer	***- High natural mortality of pests (eggs, young larvae)***	-
Decreases in minimum daily temperature	***- High natural mortality of pests (all stages)*** ***- Reduced egg-laying activity***	-
Occurrence of spring frost Occurrence of hailstorms	***Emergence of diseases***	***- Adequate treatments for each species ;*** ***- Cultural techniques;*** ***- Choice of resistant olive cultivars***
Increases in rainfall and humidity + no increases in temperatures	***Increased incidence of pests and diseases***	***- Adequate treatments for each species*** ***- Protection of pests' natural enemies;*** ***- Cultural techniques;*** ***- Choice of pest resistant olive cultivars***

Temperature increase above 35^{0}C has been identified as ***highly impacting on the natural mortality*** of some of the most noxious olive pests, namely the olive fruit fly (*Bactrocera oleae* Gmel.), olive moth (*Prays oleae* Bern.), and olive bark beetle (*Phloeotribus scarabaeoïdes* Bern.). Additionally, if the temperature increase occurs during late spring and summer, it halts olive psyllid (*Euphyllura olivina Costa*) activity and induces female summer diapause (i.e., the period of suspended development of olive psyllid, especially during unfavourable environmental conditions), with ***severe effects on the eggs and young larvae.*** The association of this increase in temperature with water stress can lead to a natural mortality rate of up to 90% of the olive borer (*Hylesinus oleiperda* Fabr.), which falls down to 50 % under irrigated conditions. If the temperature increase is coupled with a decrease in humidity, it ***negatively impacts on the survival of the olive moth eggs and young larvae*** inside the olive fruits (carpophagous generation) (Tombesi *et al.,* 2007).

A particular context for olive fly infestation is represented by the Mediterranean Basin, where changes in temperature are occurring unevenly, as discussed in section 5. Therefore, variable increasing and decreasing levels of infestation are expected across the basin. More specifically, a 5.9% ***increase in infestation***, with reduced variability, is predicted in Italy and France, no significant change is predicted for the Iberian Peninsula, but large declines are predicted in hotter regions such as Greece, Turkey, and the Balkans (Ponti *et al.*, 2014).

The drastic decreases in temperature have similar effects to the increases, on most of the olive pests and diseases (Proietti and Regni, 2018). For example, in the case of olive fruit fly, low winter temperatures ***curb the ovipositional (egg-laying) activit***y (Tombesi *et al.,* 2007).

Additionally, occurrence of spring frosts could damage young vegetation, causing small lesions that may ***favour the settlement of one of the most damaging diseases for olive trees, the olive knot*** (*Pseudomonas savastanoï pv. savastanoï* (Smith)) (Proietti and Regni, 2018). The occurrence of hail storms has very similar effects, as discussed in section 6.1.1.2.

Increases in rainfall and humidity can contribute to ***increased activity of olive trees' pests***, if all other conditions are met. For example, mild temperatures in winter, early spring and autumn, accompanied by considerably increased rainfall, particularly in autumn, are ***favourable for olive psyllid activity*** (Tombesi *et al.*, 2007). Increased air humidity may also be ***beneficial for the emergence and activity of the olive borer and olive moth***, as their survival rates decrease considerably under dry conditions, as discussed earlier in this section. Moreover, if increased humidity is occurring at temperatures between 18 and 21^{0}C, the ***optimal conditions for development of olive leaf spo***t *(Cycloconium oleaginum* CAST.) are met. Also, at increased ambient humidity, the ***infection rate of olive fruits with olive anthracnose (Gloeosporium olivarum ALM.) rapidly increases.***

Taking into consideration the effects of changes in temperature and rainfall on olive trees' pests, it is apparent that temperature and humidity determine the geographical location of the species' incidence. More precisely, particular increases in olive fly populations are expected in the mild coastal olive growing areas of southern Europe, while the lowest populations are projected inland, at higher altitudes, as well as in areas where summer temperatures are close to, or exceed the, fly's upper thermal limits (Ponti *et al.*, 2014). For the olive moth, the areas are restricted to olive growing coastal areas or mild, damp regions, due to the sensitivity of the eggs to air dryness, such as the more humid parts of the Mediterranean and Black Sea Basins (Proietti and Regni, 2018). Similarly, the olive psyllid, olive bark beetle, and olive borer can be found across the less dry olive growing areas of the Mediterranean Basin. Such areas also meet the optimal conditions for development of olive leaf spot, as discussed earlier in this section. The olive growing regions exposed to hail and frost are particularly prone to the proliferation of olive knot disease, as discussed earlier in this section (Tombesi *et al.,* 2007).

As general decisions suitable to the above changes in temperature and rainfall and associated negative impacts on olive pests and diseases, there can be mentioned the adequate treatments for each species. There are many possibilities, such as ***protection of the natural enemies of the pests (predators and parasitoids), cultural techniques (pruning and sucker removal, burning of infested organs, tillage and hoeing under the trunk and canopy to control soil-borne insects, such as olive moth and olive fruit fly), and the choice of olive cultivars with high tolerance or resistance***, in the sites where the climatic conditions are favourable to increased incidence of specific olive pests and diseases (Tombesi *et al.*, 2007; Proietti and Regni, 2018). Among these most common decisions, the one related to choice of resistant cultivars is not really effective in the case of olive fly. This is due to the fact that, despite its preference to lay its eggs on large, spherical, green and hard olives, it can also attack the more resistant cultivars, with other types of fruits, when the preferred ones are not readily available (Proietti and Regni, 2018).

In the olive growing areas where the impacts of climatic changes impacts are positive, in the form of increased natural mortality of pests, the olive farmers can take the opportunity to optimise olive production while keep being aware of the negative impacts of climate change, as discussed in sections 6.1.1.1, 6.1.1.2, and 6.1.1.3.

6.2. Findings from scoping workshop in Andalusia olivicultural region

In this sub-chapter, the common and different olive farming decisions affected by climate change impacts, as identified through the scoping workshop held in Antequera, Málaga, in Andalusia olive producing region, with local representative stakeholders for olive-olive oil sector (RD3) as well as through the systematic literature review. It is important to note, however, that overall, decisions identified through the literature review are mostly affected by information derived from climate scenarios and decadal predictions, whereas the decisions identified through the scoping workshop are more affected by the availability of seasonal and decadal forecasts. Therefore the overall findings from the two sources should be interpreted accordingly.

6.2.1. Key farming decisions

In the next two sections, there are presented the common and different key farming decisions as indicated by the findings of the scoping workshop and of systematic literature review. However, these decisions are not discussed here, because they are already detailed in the referred sections or documents.

6.2.1.1. Findings common to the literature review

The common key farming decisions identified through literature review and scoping workshop were those mainly affected by changes in rainfall, air humidity, and temperature, with rainfall being prevalent for the findings from the workshop and temperature – for the findings from the literature review, as illustrated in Table 6-5.

Table 6-5 Common key olive farming decisions identified through scoping workshop and literature review

<table>
<tr><th colspan="4">RAINFALL</th><th colspan="4">TEMPERATURE</th></tr>
<tr><th colspan="2">Literature review</th><th colspan="2">Workshop</th><th colspan="2">Literature review</th><th colspan="2">Workshop</th></tr>
<tr><th>Climatic changes</th><th>Decisions</th><th>Climatic changes</th><th>Decisions</th><th>Climatic changes</th><th>Decisions</th><th>Climatic changes</th><th>Decisions</th></tr>
<tr><td rowspan="3">Decrease in rainfall below minimum requirements of olive trees</td><td rowspan="3">Irrigation</td><td rowspan="5">Precipitation (rain)</td><td rowspan="5">Irrigation</td><td rowspan="2">Decrease in temperature below the minimum requirements of olive trees</td><td rowspan="2">Settling olive orchards on hill slopes</td><td rowspan="5">Temperature</td><td>Design of plantation</td></tr>
<tr><td>Irrigation</td></tr>
<tr><td>Increases in temperature during fruit ripening</td><td>Harvest at fruit removal force < 3-3.5</td><td>Harvest; olive yield estimation</td></tr>
<tr><td rowspan="2">Uneven distribution and reduced amount of rainfall during fruit setting and development stages</td><td>Irrigation during the vegetative period (annual rainfall > 700 mm);</td><td rowspan="2">Increase in summer temperature</td><td>Water stress reducing measures;</td><td>Irrigation</td></tr>
<tr><td>Irrigation during vegetative and productive period (annual rainfall 500 - 700 mm);</td><td>Management (of crop genetic factors and) of soil conditions</td><td>-</td></tr>
</table>

	Irrigation + additional water stress reducing measures (annual rainfall 400 - 500 mm)			Uneven increase in temperature across regions	*Management (of crop genetic factors and) of soil conditions*		-
Decreases in rainfall in spring and summer	*Water stress reducing measures*				*Irrigation*		-
				-	-		-
Increases in rainfall and air humidity + no increases in temperatures	*Adequate treatments for each species*	Air humidity	*Phytosanitary treatments*	-	-		-
	Cultural techniques		*Pruning*	-	-		-

In relation to rainfall**,** the ***results from the workshop*** indicated ***phytosanitary treatments, irrigation and pruning*** as the most critical decisions affected by the ***amount of rain and the level of air humidity*** occurring all year around (phytosanitary treatments), between April and October (irrigation), and between January to March (pruning), as illustrated in Table 3-1 of deliverable D 2.1. (RD3).

Similarly, the ***findings from the literature review*** indicated different levels of irrigation, ***additional water stress reducing measures, phytosanitary treatments and pruning*** as critical decisions affected by ***decreases and increases in rainfall and air humidity, as well as uneven distribution of rainfall*** at critical stages during olive trees' development (Table 6-5). More specifically, irrigation was identified as the most common critical decision in areas susceptible to decrease in rainfall amount below minimum requirements of olive trees, as discussed in section 6.1.1.1. Different levels of irrigation, applied at different stages (only vegetative or both vegetative and production stages), coupled with additional water stress reducing measures (careful control of weeds, low plant density, adequate intensity of pruning), were applied in areas with reduced and unevenly distributed amount of rainfall during olive fruit setting and development stages, as discussed in section 6.1.1.2. Adequate phytosanitary treatments and cultural techniques, among which severe pruning, were adopted in the areas where the increases in rainfall and air humidity were beneficial for emergence of olive pests and diseases, as discussed in section 6.1.1.3.

In relation to temperature, the ***results from the workshop*** indicated ***irrigation, harvest, olive yield estimation, and design of plantation*** as the most critical decisions affected by the ***minimum and maximum temperature*** occurring between April and October (irrigation), October and March (harvest), October and February (olive yield estimation), January and April and In September-October (plantation design), as illustrated in Table 3-1 of deliverable D 2.1. (RD3) In the wider context, Andalusia is located in the Mediterranean Basin, which is characterized by unevenly distributed impacts of increases in temperature, as discussed in section 5. Consequently, the adapting strategies may vary accordingly across the different parts of the basin and of Andalusia region itself.

Similarly, the ***findings from the literature review*** indicated the ***settlement of olive plantations, irrigation, harvest time, and management of soil condition***s as critical decisions affected by the ***increases and decreases in temperature*** above and below maximum and minimum requirements of olive trees, increase of temperature at critical development stages of olive crop, as well as at critical times during the growing season, and uneven increase in temperature across regions (Table 6-5). More precisely, settlement of olive plantations on hill slopes, at intermediate altitudes, was adopted in areas susceptible of decreases in temperature below the minimum requirements of olive crops, as discussed in section 6.1.1.1. Irrigation was applied in the areas where there were expected increases in temperature above the maximum requirements of the olive crops, as discussed in section 6.1.1.1., as well as in the areas where these increases occurred during summer (section 6.1.1.3), and in the events of uneven increase in temperature across different olive growing areas (section 6.1.1.3). Harvest time was carefully planned, in order to prevent alteration of olive fruit quality, and, therefore, of olive oil, in areas where increases in temperature occurred during fruit ripening, as discussed in section 6.1.1.2. The management of soil conditions, including vegetation cover, coupled with management of crop genetic factors, were adopted in olive growing areas with uneven increase in temperature, as discussed in section 6.1.1.3.

6.2.1.2. Additional findings to the literature review

The different key farming decisions identified through literature review and scoping workshop were mainly affected by changes in rainfall, air humidity, temperature, and windiness, with rainfall being prevalent for the findings from the workshop and temperature – for the findings from the literature review, as illustrated in Table 6-6.

In relation to rainfall, the ***findings from the workshop*** indicated ***phytosanitary treatments, fertilization and planning of fertilization, soil labouring, olive yield estimation and harvesting, and plantation design*** as the most critical decisions affected by the ***amount of rain*** falling all year around (phytosanitary treatments, soil labouring), between March and October (fertilization), in January and February (planning of fertilization), between April and October (irrigation), between October and March (harvesting), between October and February (olive yield estimation), from January to April and from September to October (plantation design), as illustrated in Table 3-1 of deliverable D 2.1. (RD3). Additionally, the levels of ***air humidity*** occurring between March and October, April and October, and between January and March impacted on ***fertilization, irrigation, and pruning***, respectively (Table 3-1; RD3).

Differently, the ***findings from the literature review*** indicated ***policy making to support economic growth and the shift from irrigated cereals to irrigated olive orchards*** as the most common critical decisions affected by the ***decreases in rainfall*** below minimum requirements of olive trees, when coupled with economic drivers (decrease in cereals' market price), as discussed in section 6.1.1.1. The ***management of crop genetic factors and of soil conditions*** was identified as the most common critical decision affected by the ***decreases in rainfall*** occurring in spring and summer, as discussed in section 6.1.1.3. The ***protection of pests' natural enemies and the choice of olive cultivars resistant to pests and diseases*** were identified as the most common critical decisions affected by the ***increases in rainfall and air humidity*** in areas susceptible to increased emergence of olive pests and diseases, as discussed in section 6.1.1.4.

In relation to temperature, the ***findings from the workshop*** indicated ***pruning, fertilization and planning on fertilization, and soil labouring*** as the most common critical decisions affected by the ***temperatures*** occurring all year around (soil labouring), from March to October (fertilization), in January and February (planning on fertilization), and between January and March (pruning), as illustrated in Table 3-1 of deliverable D 2.1. (RD3).

Differently, the ***findings from the literature review*** indicated the ***settling olive orchards near large masses of water*** as the most common critical decision affected by the ***decreases in temperature*** below minimum requirements of olive trees, as discussed in section 6.1.1.2. In the same section, the ***rescheduled planting date***, for cold environments, along with the ***planting during winter***, for hot environments, were identified as the most common critical decisions affected by the ***occurrence of frequent lower than optimum temperatures at planting time***. The ***adjusted shape of olive tree*** was identified as the most common critical decision affected by the ***occurrence of prolonged increases of temperature*** above the maximum supported by olive trees (section 6.1.1.2.). The ***abandon of farms at risk, adjusted agronomic practices, the decisions based on climatic information on local disparities, and the management of crop genetic factors and of soil conditions*** were identified as the most common critical decision affected by the ***uneven increase in temperature*** across regions, as discussed in section 6.1.1.3.

Table 6-6 Different key olive farming decisions identified through scoping workshop and literature review

RAINFALL				TEMPERATURE				WINDINESS				EXTREME EVENTS	
Literature review		Workshop		Literature review		Workshop		Literature review		Workshop		Literature review	
Climatic changes	*Decisions*	Climatic changes	*Decisions*	Climatic changes	*Decisions*	Climatic changes	*Decisions*	Climatic changes	*Decisions*	Climatic changes	*Decisions*	Climatic changes	*Decisions*
Decrease in rainfall below minimum requirements of olive trees + economic drivers	*Policy making to support economic growth*	Precipitation (rain)	*Fertilization*	Decreases in temperature below minimum requirements of olive trees	*Settling olive orchards near large masses of water*	Temperature	-	Increased severity of windiness	*Choice of areas near large water masses*	Wind speed and direction	*Phytosanitary treatments*	Risk of late spring/ early autumn frost	*Choice of areas near water masses*
	Shift in crops		*Planning of fertilization*	Frequent lower than optimum temperatures at planting time	*Rescheduled planting date (in cold environments)*		-		*Use of living windbreaks or mechanical barriers*		*Harvest*		*Earlier harvest date*
Decreases in rainfall in spring and summer	*Management of crop genetic factors and of soil conditions*		*Soil labouring*		*Planting during winter (in hot environments)*		-	-	-		*Pruning*	Occurrence of spring frost	*Adequate treatments for each species*
Increases in rainfall and air humidity + no increases in temperatures	*Protection of pests' natural enemies*		*Phytosanitary treatments*	Prolonged increases of temperature above the maximum supported by olive trees	*Adjusted shape of olive tree*		*Pruning*	-	-	-	-		*Cultural techniques*
	Choice of resistant olive cultivars (to pests and diseases)		*Harvesting*	Uneven increase in temperature across regions	*Abandon of farms at risk*		-	-	-	-	-		*Choice of resistant olive cultivars*
-	-		*Olive yield estimation*		*Adjusted agronomic practices*		*Fertilization*	-	-	-	-	Frequent hailstorms	*Adequate treatments for each species*

-	-		*Design of olive plantation*		Decisions based on information on local disparities		*Planning on fertilization*	-	-	-	-		*Cultural techniques*
-	-		*Fertilization*		Management of crop genetic factors and of soil conditions		*Soil labouring*	-	-	-	-		*Choice of resistant olive cultivars*
-	-	Air humidity	*Irrigation*		-	-	-	-	-	-	-	Prolonged and/or repeated water stress	*Water stress reducing measures*
-	-		*Pruning*		-	-	-	-	-	-	-	-	-

In relation to windiness, the ***findings from the workshop*** indicated ***phytosanitary treatments, harvest and pruning*** as the most critical decisions affected by the ***speed and direction of wind*** occurring all year around (phytosanitary treatments), between October and March (harvest), and between January and March (pruning), as illustrated in Table 3-1 of deliverable D 2.1. (RD3).

Differently, the ***findings from the literature review*** indicated the choice of ***olive cultivation areas near large water masses and the use of living windbreaks or mechanical barriers*** as the most common critical decisions affected by the increased severity of windiness, as discussed in sections 6.1.1.1. and 6.1.1.2., respectively.

Additional different critical farming decisions identified through ***literature review*** were affected by the occurrence of extreme events, as shown in Table 6-6. More specifically, the choice of ***areas near water masses and earlier harvest date*** were identified as the most common critical decision in the areas where there was ***risk of late spring/ early autumn frost,*** as discussed in sections 6.1.1.1. and 6.1.1.2., respectively. The adequate ***phytosanitary treatments, the cultural techniques (severe pruning, and burning of infested olive tree parts), and the choice of resistant olive cultivars*** were identified as the most common critical decisions in the areas with increased ***risk of spring frost and frequent hailstorms***, which both facilitate increases in disease emergence, as discussed in section 6.1.1.4. The ***water stress reducing measures, such as careful control of weeds, low plant density, adequate intensity of pruning,*** were identified as the most common decision in the areas with ***risk of prolonged and/or repeated water stress***, as discussed in section 6.1.1.2. In the wider context, among these risks, prolonged water stress contributing to increased drought severity are expected to become common across the Iberian Peninsula, as well as the extreme summers across southern Europe, as discussed in section 4.4. Therefore, additional measures may be required for the olive farmers to adapt to these changes.

6.2.2. Key socio-economic decisions

In this section, there are presented the key socio-economic decisions as indicated by the findings from the systematic literature review and from the scoping workshop (Table 6-7).

The decisions identified through the literature review were affected by a combination of climatic and economic drivers, for which reason they were also presented in previous relevant sections. However, in this section, the socio-economic decisions identified through literature review are only discussed as being affected by the economic drivers, because the impacts related to the climatic drivers were previously discussed. Differently, the socio-economic decisions identified through the scoping workshop were only associated with climatic drivers, and are discussed in the referred source (RD3).

6.2.2.1. Findings from literature review

The most common socio-economic decisions identified through the literature review were mainly affected by changes in rainfall and temperature in association with changes in market price and optimum economic yield.

At macro-economic level, the most common identified decision was ***policy making to support national economic growth,*** as affected by the ***decrease in rainfall below minimum requirements of olive trees occurring simultaneously with a decrease of cereals' market price***. Firstly introduced in section 6.1.1.1., in association with the change in the olive growing areas towards their expansion, this decision indicates that the climatic drivers should not be considered in isolation when analysing the impacts and related decisions of climate change on olive farming.

At regional level, the ***shift from cereals to olive trees*** was the most common identified decision affected by the ***same combination of drivers***. These adapting decisions, recommended for the policy making relating to the vulnerability of the irrigation system to climate change in a Spanish district facing severe water shortages, were balanced in terms of economic, social and environmental components contributing to an increasing trend of olive growing areas under harsh environmental conditions, as discussed in section 6.1.1.1.

Across the olive growing areas in the Mediterranean Basin, besides the climatic drivers (unevenly distributed increases in temperature and drought occurrence across area; section 5), there were identified other drivers, such as agronomic practices, for example, as majorly determining a high variability of optimum economic olive yields, as firstly discussed in section 6.1.1.3. Therefore, ***development of the ability to quantify climate risks*** associated with specific geographical locations for olive crop was identified as a reliable adaptation strategy in parts of Spain with southern Mediterranean coastal climatic conditions, where ***olive production*** has been found ***to be at risk*** without irrigation. In the context of increasing risks posed by climate change impacts on olive farming, as one of the agricultural sub-sectors, such strategy might serve as a guide for the policy makers and farmers along their pathway towards sustained socio-economic and environmental development of olive growing areas in the Mediterranean Basin (Iglesias *et al.*, 2010).

Table 6-7 Key olive farmers' socio-economic decisions identified through literature review and scoping Workshop

Literature review		Workshop	
Driver	***Decisions***	**Driver**	***Decisions***
Decrease in rainfall below minimum requirements of olive trees + change in market price	*Policy making to support national economic growth*	Temperature Precipitation	*Fertilizer purchase/sale*
	Shift in crops	-	*Modernization of harvesting machinery*
Uneven increase in temperature across regions	*Irrigation + development of skills to quantify climate risks*	-	*Machinery labour*

6.2.2.2. Findings from the scoping workshop

Differently, the key socio-economic decisions identified through the scoping workshop were mainly affected by the ***climatic drivers (temperature and precipitation).*** More specifically, ***the purchased and sale of fertilizer*** were affected by the temperature and rainfall occurring between August and March, as illustrated in Table 3-1 of deliverable D 2.1. (RD3). Other identified socio-economic decisions related to modernization of harvesting machinery and machinery labour (RD3).

6.2.3. Climate information needs

The findings presented in this section indicate the climate information needs identified through the scoping workshop for the representative olive farming systems operating under representative climate conditions for olive cultivation and are discussed in the referred source (RD3). Due to their representativeness, the identified climate information needs may be considered for other olive growing areas located in similar climatic context, all other factors being considered equal. However, caution is needed in interpreting their general usefulness to the extent to which the decisions for which this information can be used may be also influenced by factors such as the relief, the management and cropping system, and the irrigation strategy (RD3).

The most critical climate information was identified as 7 day meteorological forecast, followed, in decreasing order of importance, by forecasts for the next month, next 14 days, next 3 days, next 3 to 6 months, next year, next day, and for the next 10 to 30 years, as illustrated in Figure 3-2 in deliverable D 2.1. (RD3).

The level of importance of this climate information was based on its usefulness for making short and long-term decisions. More precisely:

- ***the 7 day forecast*** was identified as useful for ***all short-term decisions*** relating to all the ***field activities*** ;
- the ***forecasts for next 3 days, next 14 days and the next month*** were overall identified as less useful for ***all the short and long-term decisions;***
- the ***forecasts for the next day, next 3 to 6 months and next year*** were identified as particularly useful for ***the decisions related to harvest activities;***
- the ***forecast for the next 10 to 30 years*** was identified as useful only in relation to ***long-term decisions such as settling of new olive plantations and the modernization of existing ones*** (RD3).

7. VULNERABILITY OF *GRAPES - WINE* SECTOR TO CLIMATE VARIABILITY AND CHANGE

7.1. Findings from the literature review

In this sub-chapter, there are presented the most common identified climatic changes and related negative and positive impacts on grape vines and grapes, as well as the farming decisions relating to these impacts.

Noteworthy, all the tables in this section are presented with alternative shaded and blank areas, to enhance horizontal visualisation for similar types of climate change impacts and decisions.

7.1.1. Climate change impacts, and critical decisions, on European viticulture

The most common identified impacts were on grapevine cultivation areas, grape varieties, grapevine development and phenology, grape and wine quality, pests and diseases, and yield.

Noteworthy, these impacts were mostly assessed through modelling and projecting work, unless otherwise stated in text.

7.1.1.1. Cultivation areas

The identified climate change impacts on grapevine cultivation areas were mostly related to changes in temperature, day length, and sea level (Table 7-1) and are further discussed, where possible, together with associated identified grape farmers' decisions.

Table 7-1. Climate change impacts on grapevine cultivation areas and critical decisions

Expected climate change	*Impacts*	*Critical decisions*
Increase in temperature	***Northward expansion of areas***	***Settling the grapevine plantation at thermally suitable altitude on hillsides***
	Reduced suitability of southern areas	- ***Settling the grapevine plantation at thermally suitable altitude on hillsides*** - ***Adjusted training techniques and row orientation, to reduce sunlight exposure***
	Extended areas suitable for red grape varieties	***Settling the grapevine plantation at thermally suitable altitude on hillsides***
	Reduced areas suitable for white grape varieties	***Settling the grapevine plantation at thermally suitable altitude on hillsides***
Dry conditions	***Reduced suitability of southern areas***	- ***Irrigation*** - ***Adjusted trellis height*** - ***Management of soil conditions*** - ***Use of drought resistant varieties*** - ***Introduction of winter cover crops***
Increase in day length	***Increased suitability of northern areas***	-
Rise in sea level	***Reduced suitability of coastal areas***	-

The continuous and rapid shifts in weather patterns, as impacts of climate change, have been identified as drivers of suitability of grapevine growing regions for specific types of wine (reviewed in Teixeira *et al.*, 2013). At regional level, these shifts, and associated impacts, recorded different trends for northern European areas or northern parts of southern areas compared to southern European areas or southern parts of northern areas. These trends may be justified by the regional disparities in terms of climate variability and change across northern and southern regions, as discussed in section 4.

More specifically, the projected increase in temperature may positively impact on ***northwards expansion of grapevine growing areas***, with emergence of new suitable areas (e.g. England and even Sweden), while it may negatively impact on ***southern regions***, in terms of their ***reduced suitability for grapevine cultivation*** due to the exceedance of their optimum thermal conditions for the existing varieties, Neethling *et al.* (2016).

However, the climatic suitability varies across the northern grapevine growing and wine producing regions, as reflected by Huglin's heliothermal index (HI). This index, calculated by using mean and maximum air temperature when the grapevine metabolism processes are active and the day length coefficient, is commonly used for estimating the climatic regional suitability for cultivation of specific grape varieties. Its values range from ≤1500 (for very cold regions) to >3000 (for very warm regions) (Irimia *et al*., 2013). Across northern European regions, the mean value of this index (HI<1500), indicates expected overall unsuitable climatic conditions for warmer climate grape varieties, either for the current conditions or for the future ones (Malheiro *et al.* 2010). One example is Scotland, which, despite the expected increase in summer temperature, is projected to remain too cold for commercially viable wine grape production Dunn *et al.* (2017). However, it has been argued that at a value of HI ≤1500, the early cultivars are expected to reach maturity, especially in the case of the white varieties (e.g., Muller-Thurgau, Pinot blanc, Gamay, Gewurztraminer; Irimia *et al.*, 2013).

Other bioclimatic indices give more detailed indications of the European temperate wine regions' suitability for different grape varieties, as discussed next. More exactly, the average temperature of the warmest month (July) with values between 8.5 and 9.3 ^{0}C indicate the suitability for white table wines, sparkling wines and wines for distillates, whereas the values between 10.1 and 11.2 ^{0}C indicate a suitability for red and white quality wines. The global radiation, expressed as kcal/cm^2 between 01.IV-30.IX, with values 80.0 and 83.9 indicate the suitability for white table wines, sparkling wines and wines for distillates, whereas the values between 87.0 and 92.0 indicate the suitability for red and white quality wines. The rainfall during the growing season, expressed as mm between 01.IV - 30.IX, with a value > 390 mm, indicates the suitability for white table wines, sparkling wines and wines for distillates, whereas the values between 251 and 390 mm indicate the suitability for red and white quality wines. The sum of fractions of daily temperatures > 10°C (Σtu°C) between 1.IV and 30.IX, with values between 1045 and 1200 ^{0}C, indicate the suitability for white table wines, sparkling wines and wines for distillates, whereas the values between 1401 and 1675 ^{0}C indicate the suitability for red and white quality wines. The length of growing season with values between 160 and 175 days indicate the suitability for white table wines, sparkling wines and wines for distillates, whereas the values > 190 indicate the suitability for red and white quality wines. The Bioclimatic viticultural index (Ibcv) between 1.IV and 30.IX, with values between 3.9 and 5.0 indicate the suitability for white table wines, sparkling wines and wines for distillates, whereas the values between 8.1 and 13.0 indicate the suitability for red and white quality wines. The index of oenoclimatic aptitude (IAOe), between 1.IV and 30.IX, with values between 3793 and 4300 indicate the suitability for white table wines, sparkling wines and wines for distillates, whereas the values > 4600 indicate the suitability for red and white quality wines (Irimia *et al.*, 2013).

For southern European regions, and southern parts of northern regions, the mapping of temperature analogues indicates more homogenous projected climatic suitability of these areas for wine grape production (Dunn *et al.*, 2017). However, the future suitability of these regions is debateable. Some authors (Malheiro *et al.*, 2010) argue that regions with high values of HI, such as northern and central France, and south-western Germany are expected to be highly suitable for high quality wines. Others argue that at a value of HI>2400, corresponding to warm climate, the heliothermal needs for grape varieties, even for late ones, to ripen are already exceeded (Irimia *et al.*, 2013). In the southern areas with strong sunlight, the grape farmers may adjust the ***training techniques and the row orientation*** such as to reduce the heat stress (reviewed in Mozell and Thach, 2014).

One decision which might help to adjust the generally variable suitability of differently located grapevine cultivating areas, as being affected by the increased temperatures, is to ***exploit,*** as needed, ***the difference in seasonal temperatures between the top and the bottom of hillsides*** (Neethling *et al.*, 2016).

Additionally to exceeding heliothermic needs, the dryness index (DI < -100 mm) indicates that some parts of southern Europe are projected to become very dry (e.g. southern Iberia, Italy and south-eastern Balkan Peninsula), so that ***irrigation*** of vineyards is expected to maintain the suitability of wine regions form these areas for maintaining the wine yield and quality at current levels (Malheiro *et al.,* 2010).

Currently, the optimum climatic conditions are known to be within the approximate latitude belt of 45 to 55°N. The high altitude, even mountainous, parts of the southern regions are expected to encounter more favourable climatic conditions for increased number of optimal years for wine grape production. In contrast, this number is expected to decrease at low altitudes in southern European grapevine cultivating areas, due to increasingly drier conditions in these areas (Malheiro *et al.*, 2010). In such instances, grape farmers may be expected to ***irrigate*** their vineyards, ***adjust trellis hight, manage the soil conditions*** to improve water storage during the growing period (Resco *et al*., 2016) and make use of ***drought resistant varieties*** (Neethling *et al.*, 2016). Additionally, in such areas, they can ***introduce winter cover crops***, to improve soil water storage, provided the viticultural areas are suitable for such crops (reviewed in Mozell and Thach, 2014).

Interestingly, the increased day length in high altitude areas, occurring during the grapevine growing period, is expected to lead to a ***northward extension of the viticultural areas*** by partially compensating for lower temperatures in comparison to the low altitudes areas (Malheiro *et al.*, 2010).

A projected rise in the sea level up to five meters would represent a flood threat of some of the world greatest vineyards and wine producing regions, such as portions of Bordeaux and Portugal (reviewed in Mozell and Thach, 2014). These regions are located in ***coastal regions***, where the climatic changes may pose the ***risk of sea level rise***, as discussed in section 5.

In brief, the above climatic drivers may open up opportunities to be seized in the northern areas or the northern parts of southern areas, as well as losses in the southern areas or the southern parts of northern areas. Therefore, the decisions of grape farmers should be adjusted accordingly.

The results of the cluster analysis indicated very low values (between 0.02 and 0.09) and not statistically significant (average *P*-value 0.89) of the Pearson coefficient for the analysed correlations between the identified climate change impacts and associated critical decisions. The identified most relevant correlation was between the increased suitability of most southern areas in the temperate climate for red grape varieties, as an impact associated with increased temperature, and the decision to irrigate the vineyards where necessary (Pearson coefficient 0.06). The low values of Pearson coefficient for the investigated correlations and the extremely low number of relevant identified correlations indicate that there may be other factors to be identified, more important than the ones discussed above, which may have heavier impact on grapevine cultivating areas and associated decisions.

7.1.1.2. Grape varieties

The identified climate change impacts on grape varieties were mostly related to changes in temperature and CO_2 emission level (Table 7-2) and are further discussed, where possible, together with associated identified grape farmers' decisions.

Table 7-2. Climate change impacts on grape varieties and critical decisions

Expected climate change	***Impacts***	***Critical decisions***
Increase in temperature	- ***Shift in grape cultivars***	- ***Use of warm climate clones***
	- ***Low level of productivity (red and white cultivars)***	- ***Introduction of new varieties;*** - ***Rootstocks with longer cycle;*** - ***Late-ripening clones***
Increase in temperature+ elevated CO_2 level+ drought	- ***Higher resistance of red cultivars;*** - ***Lower resistance of white cultivars***	- ***Use of drought resistant rootstocks***

The projected increase in temperature is expected to determine shifts in grape cultivars, for example. More specifically, in south-western Germany, it is expected an increasing ***shift from traditional white wine grape cultivars to red wine grape cultivars***, following the observed temperature increase of 1.7^{0}C-2.5^{0}C between 1974 and 2015 and an expected further 1^{0}C-2.0^{0}C increase over the next 20-50 years. In this context, the grape farmers may be expected to use new "Riesling" and other clones of traditional ***white cultivars that will be more suited to the warmer climate*** compared to the traditionally used clones (Koch and Oehl, 2018). However, the use of such clones is subject to compliance with the existing normative (Resco *et al.*, 2016).

When projected temperature increase occurs in the beginning of the growing season, both ***white and red wine grape cultivars*** are expected to show ***low levels of productivity*** in Douro wine region, Portugal (Fraga and Santos, 2017). In this context, the grape farmers may be expected to decide for ***introduction of new varieties***, different to the ones traditionally grown in the region, which might show higher levels of productivity but are very likely not to produce the types of wines with commercial interest (Resco, *et al.,* 2016). As an alternative, grape farmers may ***use rootstocks that induce a longer cycle, and select late-ripening clones***. These adaptations will not change wine typicity, as the choice of rootstocks helps the grapevine adaptation to the physical and hydric properties of the soil and conditions its overall functioning (Neethling *et al.*, 2016).

When the projected temperature increase occurs at the same time with elevated CO_2 levels and drought, the Tempranillo ***red cultivars*** are expected to be ***more resistant*** to these stresses compared to Tempranillo white cultivars, in terms of levels of productivity (INRA, 2016). To ensure the optimum level of productivity across the red and white cultivars, grape farmers are advised to ***decide for drought resistant rootstocks***, which play a critical role in adaptation of vineyards to severe water deficits (Neethling, *et al.,* 2016).

The results of the cluster analysis indicated rather low values (between 0.15 and 0.06) and not statistically significant (average *P*-value 0.94) of the Pearson coefficient for the analysed correlations between the identified climate change impacts and associated critical decisions. The identified most relevant correlations were:

(a) between the shift from white to red cultivars, as an impact associated with increased temperature, and the decision to use clones of traditional white cultivars that will be more suited to the warmer climate (Pearson coefficient 0.15);
(b) between the shift from white to red cultivars, as an impact associated with increased temperature, and the decision to use late-ripening clones (Pearson coefficient 0.06).

On one hand, these correlations emphasize the importance of managing the genetic potential to adapt to impacts of climate change such as increase in temperature above the maximum requirements of the grapevines. On the other hand, the low values of the Pearson coefficient indicate there may be other factors than the ones discussed above, which may have heavier impact on grape varieties, and associated decisions, and which need to be identified by grape farmers for efficient decisions in relation to impacts of climate change.

7.1.1.3. Grapevine development and phenology

It has been acknowledged that grape vine phenology, meaning the date on which bud break, flowering, and véraison (i.e., onset of ripening) occur, are primarily driven by temperature (Van Leeuwen and Darriet, 2016). In this review, the identified climate change impacts on grape vine development and phenology were mostly related, in the order of importance, to changes in temperature, CO_2 emission level, rainfall, water stress, salinity, and frost, as well as occurrence of water stress (Table 7-3), and are further discussed, where possible, together with associated identified grape farmers' decisions.

Table 7-3. Climate change impacts on grape vine development and phenology and critical decisions

Expected climate change	***Impacts***	***Critical decisions***
Increase in temperature	***Earlier phenological timing***	- ***Early leaf removal;*** - ***Use of rootstocks with longer cycle;*** - ***Use of late-ripening clones;*** - ***Adapting training system***
	Shorter growing season	
	Reduced grape weight	
	Berry sunburn and shrivelling	- ***Late leaf removal***
Increase in temperature + moderately dry conditions	***High quality wines***	-
Decrease in temperature	***(during veraison stage) incomplete maturation***	-

Decrease in temperature+ rainy conditions	***(at flowering time)*** - ***Reduced fruit set;*** - ***Reduced pollen viability***	-
Elevated CO_2 levels	- ***Heterogenous phenology timing;*** - ***Enhanced grapevine vigour and growth;*** - ***Increased resistance to cold;*** - ***Slight antifungal resistance***	-
Elevated CO_2 levels+ increased temperature	- ***Accelerated fruit development;*** - ***Early ripening***	- ***Late leaf removal;*** - ***Irrigation***
Decrease in summer rain+ drought	- ***Earlier ripening***	- ***Increase vine load;*** - ***Drought resistant rootstock and grape varieties;*** - ***Adapting the training system;*** - ***Soils with moderate soil-water-holding capacity***
Salinity	- ***Reduced grapevine growth***	- ***Irrigation***
Repeated frost	***- Complete destruction of grapevines***	-

The changes in temperature were found to both negatively and positively impact on mainly the grapevine phenological timing and duration of growing season, but also on grape development. The increased temperature across the wine European regions determined earlier timing of main phenological stages (bud break, flowering, and veraison), as well as of the harvest date, for the majority of the grape varieties.

More precisely, for both red and white Tempranillo varieties, the observed ***budburst date*** has ***shifted earlier*** by 4.49 days for each degree of annual temperature increase, the ***stage between budburst to flowering – by 3.29 days***, and ***the stage from flowering to harvest - by 2.57 days***, in Croatia (Martínez-Lüscher *et al.*, 2016). The grape varieties from Tuscany's Chianti wine region have been found to ***ripe far too early*** under rising temperature conditions (reviewed in Mozell and Thach, 2014), which may affect the tipicity of the wines. For Cabernet Sauvignon and Merlot, a prolonged temperature increase of 1.3^{0}C has been reported to determine ***changes in the dates of all the phenological events and in the length of the growing season,*** in Bordeaux wine region (reviwed in Teixeira *et al.*, 2013). A ten year increase in growing season temperature by 1°C has been observed and reported to have ***shortened the growing season by 27 days*** for the early-ripening Bouvier grape variety and by 15 (White Riesling) to 21 (Welschriesling) days for late-ripening varieties, in Slovenia (Vršič and Vodovnik, 2012). In the wider context, all phenological timings are projected to occur earlier in southern/coastal areas of Europe as opposed to central/northern areas, which are expected to occur later (Fraga *et al.*, 2016).

The development of grapes may be affected both negatively and positively by the increase in temperature.

- Negatively, prolonged periods with temperatures above 30 °C may cause a reduction in photosynthesis rate, with consequent berry size and weight reduction (reviewed in Teixeira *et al*. 2013). Also, the occurrence of summer heat stress has been observed and reported to aggravate berry sunburn and shrivel disorders (Gatti *et al.*, 2015).
- Positively, an increase in temperature from 20 °C to 30 °C has been reported to have ***increased the weight of bunch primordia*** (preformed inflorescences in the latent winter buds) fourfold in Riesling variety, while Shiraz was unaffected, potentially because red varieties (Shiraz) appear to tolerate warm conditions better than the white ones (Riesling) (reviewed in Schultz, 2016), and therefore may be less responsive to increases in temperature. If the increase in temperature is projected to occur simultaneously with moderately dry conditions, these are considered the most favourable conditions for the ***production of high quality wines***, which represents an advantage of most of the southern over most of the northern European wine regions (Malheiro *et al.*, 2010).

The projected occurrence of low temperature at veraison stage, in August and September, is expected to affect the level of grape maturation, with negative consequences on wine quality (Lorenzo *et al.*, 2013). This scenario is more likely to occur in northern wine regions. Moreover, a decrease in temperature, in combination with rainy conditions at flowering time, have been reported to determine ***reduced fruit set and reduced pollen viability***, resulting in overall loose clusters for Tempranillo Blanco variety. These impacts are expected for vineyards of the same age, similarly managed, but located at different altitudes (INRA, 2016). The occurrence of elevated levels of CO_2 have been identified to have impacts on phenological timing, grapevine development and resistance to cold. The general impact on phenological timing was mainly towards ***heterogeneous anticipation of the phenophases***. More specifically, the budburst–flowering interphase is expected to be longer across almost all the European wine regions, with the exception of some areas in coastal Portugal and southern Spain. Some areas of northern Spain and France may present even longer periods (as much as 20 days) (Fraga *et al.*, 2016). Other findings from northern Spain reported observed accelerated fruit development and earlier grape ripening by 6.75 days under elevated CO_2 conditions combined with increased temperature (Martínez-Lüscher *et al.*, 2016) and by 3-3.9 days under similar conditions, but combined with partial irrigation (Salazar-Parra *et al.*, 2018).

Grapevine development, in terms of ***vigour and growth,*** is expected to be ***enhanced*** by elevated levels of CO_2 (550 ppm) for both white (Riesling) and red (Cabernet Sauvignon) grape varieties (INRA, 2016).

Interestingly, the ***resistance to cold***, together with ***slight antifungal resistance***, were observed as being improved under elevated CO_2 levels (Agencia Estatal, 2015).

The amount of rainfall has been found to have direct impacts on photosynthesis rate and hence grapevine growth, as well as the further development of grape berries. A typical grapevine needs 250 mm of water during the growing season, to avoid water stress (Neethling *et al.*, 2016). However, decreased amount of summer rain and settling of drought conditions have been observed and found to induce ***earlier fruit maturation***, by increasing abscisic acid production (Cook and Wolkovich, 2016). Nevertheless, the grapes' quality, under earlier maturation conditions, remains questionable.

Water stress, as the ratio between actual and maximum plant transpiration, greatly affects grapevines' leaf area index (LAI), which is an indicator of grapevine productivity. In the areas showing no or low water stress, LAI can reach an overall maximum value of 3 m^2 m^{-2} during veraison. Near-maximum values are expected to occur only in the winemaking regions of France and northern Iberia, whereas lower values (1.5–2m^2 m^{-2}) are expected to occur in central/ western Iberia and regions in the Mediterranean and the Adriatic (Fraga *et al.*, 2016).

In the coastal regions with high risk of sea level rise (portions of Bordeaux and Portugal) and the nearby inland areas, vineyards could face ***rising levels of salinity*** in ground water which could ***affect vine growth*** (reviewed in Mozell and Thach, 2014). This is because vines are highly sensitive to salt, so its build-up can make soils unsuitable for grape production (Neethling *et al.*, 2016). It worth noting that general plant responses to salt stress have much in common with responses to drought stress, as high salt concentrations decrease the osmotic potential of soil solution, creating drought stress in plants. In addition to this osmotic constraint, salt stress also imposes ionic stress on plants, mainly in relation to (Natrium) Na^+ and (Chlorus) Cl^- accumulation (Københavns Universitet, 2013).

Occurrence of ***heavy frosts for several years in the row*** have been reported to have ***irreversibly affected*** many ***vineyards*** located at lower elevations in Czech Republic (reviewed in Brázdil *et al*., 2008).

The decisions that grape farmers can make towards adaptation to impacts of climate change related to altered grapevine and grape development, changes in phenology, and water stress are numerous, the most common reviewed ones being presented below, per category of impact.

For altered grapevine and grape development, the most common identified decisions were the leaf removal techniques, which play an important role in modulating the source-to-sink balance (i.e. balance between quantity and quality of grapes) and therefore reduce the impacts related to early shifting in phenophases and accelerated development (Bobeica *et al.*, 2015). Among these techniques, early leaf removal has been observed as being important for regulating the source-to-sink balance, while ***late leaf removal*** is important in preventing incidence and severity of berry sunburn, where needed. Additionally, exposing inflorescences to high light from the beginning of the season has been observed as contributing to the accumulation of a sufficient amount of 'sunscreen', such as flavonols and xanthophylls, and helps against later grape berry sunburn incidence (Gatti *et al*., 2015).

To delay the earlier onset of fruit maturation, grape farmers may consider ***increasing the vine crop load*** (reviewed in Mozell and Thach, 2014). This will allow complete grape maturation, on one hand, but on the other hand, it can have a negative impact on fruit composition through reduction of the tannin and anthocyanin content in red grape berries - key compounds in red wine quality (van Leeuwen and Darriet, 2016). Another approach towards delaying phenology is the ***use of rootstocks that induce a longer cycle***, as well as ***late-ripening clones***. These adaptations will not change wine typicity. Together, they can delay ripeness by approximately seven to ten days. Over the long term, ripeness can be delayed much more by the use of late-ripening varieties. Also, ***training systems is modified*** to delay phenology, because higher trunks can reduce the temperature in the bunch zone and prevent excessive temperatures on dry and stony soils in particular (van Leeuwen and Darriet, 2016).

Water stress can be relieved through ***irrigation*** in regions affected by seasonal drought (reviewed in Teixeira *et al*., 2013). However, irrigation can cause soil salinization, when winter rainfall is insufficient for leaching the salt out of the soil. Therefore, when irrigation is the only option for maintaining vineyards' productivity in a given area (i.e. under severe and prolonged drought only, as grapevine is drought resistant), deficit irrigation should be implemented, to optimize grape quality (Neethling *et al.*, 2016). Other adaptations include ***use of drought resistant rootstocks*** (140 Ruggeri or 110 Richter) and ***grape varieties***. Among these, it has been reported that Mediterranean varieties, such as Grenache or Carignan, are better adapted to dry conditions than Atlantic varieties, such as Merlot or Sauvignon blanc (van Leeuwen and Darriet, 2016). In addition, the ***training system is adapted*** to the specific vines water consumption. More exactly, in the Mediterranean region, the vine growers have developed a training system that has great drought-resistant performance: the so-called *gobelet* (Mediterranean bush vines). This system limits vine water use by combining low leaf area on a per-hectare basis (which means less transpiration) and relatively low yields (lower need for photosynthesis. The main drawback of this system is that it makes mechanical harvesting very difficult (van Leeuwen and Darriet, 2016). If considering that the grape vine water status is related both to climatic factors (rainfall and ET_0) and soil related factors (soil water-holding capacity), in the dry regions, or regions exposed to increased drought, the ***development of vineyards on soils with at least a moderate soil-water-holding capacity*** can limit the negative impact of excessive water stress, as long as winter rains is sufficient to replenish the soil water storage capacity (van Leeuwen and Darriet, 2016).

The positive impacts on grapevine phenology and development (Table 7-3) leave space for opportunities to be identified and seized by grape farmers, according to their specific needs.

The results of the cluster analysis indicated rather low values (between 0.10 and 0.24) and not statistically significant (average *P*-value 0.48) of the Pearson coefficient for the analysed correlations between the identified climate change impacts and associated critical decisions. The identified most relevant correlations were:

(a) between water stress affected LAI and the decision to irrigate the vineyards affected by seasonal drought (Pearson coefficient 0.24);
(b) between the incidence of berry sunburn and shrivel disorder, as impact of occurring summer heat stress, and the decision of late leaf removal (Pearson coefficient 0.21);
(c) between the shift in phenology timing, as an impact of increasing seasonal temperature, and the decision to increase grapevine load (Pearson coefficient 0.18);
(d) between the earlier shift in the stage from bud burst to flowering, as an impact of increasing temperature in the beginning of the season, and the decision of early leaf removal (Pearson coefficient 0.17);
(e) between the shortening of growing season for the early-ripening variety Bouvier, as an impact of increasing seasonal temperature, and the decision to load the grapevine load (Pearson coefficient 0.14).

On one hand, these correlations underline the weight of the increase in seasonal temperature and occurrence of seasonal dry conditions in terms of impacts on grapevine phenology and development. On the other hand, the low values of the Pearson coefficient for these correlations indicate that there may be other factors than the ones discussed above, which may have heavier impact on grapevine phenology and development, and associated decisions, and which need to be identified by grape farmers for efficient decisions in relation to impacts of climate change.

7.1.1.4. Grape and wine quality

The climate change related to changes in temperature, occurrence of drought and light intensity have been found to have a dramatic influence on grape chemical composition (reviewed inTeixeira *et al.*, 2013). In this review, the identified climate change impacts on grape and wine quality were mostly related, in the order of importance, to changes in temperature, CO_2 emission level, sunlight, and occurrence of water stress (Table 7-4), and are further discussed, where possible, together with associated identified grape farmers' decisions.

Table 7-4. Climate change impacts on grape and wine quality and critical decisions

Expected climate change	***Impacts***	***Critical decisions***
Abnormal increase in temperature	- ***Increase in grape sugar content;*** - ***Increase in wine alcohol content;*** - ***Decrease in grape malic acid content;*** - ***Inhibition of anthocyanins synthesis and accumulation;*** - ***More wines with "cooked flavours";*** - ***More wines with "petrol flavour";*** - ***Less wines with "herbaceous notes"***	- ***Canopy management;*** - ***Grafting over more adaptable grape varieties***
Abnormal decrease in temperature	- ***Increased grape acid content;*** - ***More wines with unripe flavours;*** - ***More astringent, even sour wines***	-
Higher cool night index	- ***Improved wine colour and flavour***	-
Elevated CO_2 levels	- ***Increase in grape sugar content;*** - ***Increase in wine alcohol content;*** - ***Increase in grape tannins content;*** - ***Decrease in oak tannins content***	-
Increased sunlight	- ***Inhibition of anthocyanin accumulation and acylation (red cultivars);*** - ***(UV-B radiation) enhanced colour, flavonol, and tannin synthesis (red grapes);*** - ***Aroma degradation and lower total acidity (white cultivars);*** - ***(UV-B radiation) off-flavours in white grapes***	- ***Canopy management;*** - ***Adapted training system;*** - ***Use of UV-B filtering nets;*** - ***Grafting over more adaptable grape varieties***
Occurrence of water stress	- ***decrease in the ratio of di-/tri-hydroxylated anthocyanins (colour of red cultivars);*** - ***decreased thiol concentration (aroma of white cultivars);*** - ***enhanced red wine quality***	- ***Shallow tillage;*** - ***Deficit irrigation techniques;*** - ***Grafting over more adaptable grape varieties***

The identified impacting changes in temperature were mainly upwards and to lesser extent downwards. The upward changes mostly impacted on the ratio of sugar and acid concentrations, alcohol content, amount and composition of phenolic compounds (e.g. anthocyanins and tannins), flavour development, and overall wine sensory profile.

More specifically, it has been reported that excessive diurnal temperature, above 30^{0}C during the growing season, negatively affects the natural ratio of sugar and acid concentrations by ***increasing the sugar, and*** therefore, ***alcohol content of grapes***, and lowering the organic acids' content, which is particularly important for white wines. This ratio change, together with an additional ***alteration of accumulation and synthesis of anthocyanins*** under similar temperature conditions (up to 35^{0}C; reviewed in Teixeira *et al*., 2013), negatively affects the overall wine sensory profile (Brázdil *et al.*, 2008; Vršič and Vodovnik, 2012; Gatti *et al.*, 2015; Neethling *et al.*, 2016; Koch and Oehl, 2018; Salazar-Parra *et al*., 2018). More precisely, higher sugar determining higher wine alcohol content alters wine flavour and mouthfeel. Reduced level of anthocyanins results in reduced "colour potential" in red wines. ***Decreased concentration of malic acid***, particularly ***in white wines***, may cause microbial instability with negative effects on wine quality (reviewed in Mozell and Thach, 2014). These concerns are generally true where the 22 °C temperature isotherm is limiting the wine grape production. Nevertheless, in the tropical areas, where this threshold is exceeded, the detrimental effects of high temperatures may be largely diminished if water supply is sufficient or the humidity is high (reviewed in Schultz, 2016). However, these changes in wine grapes' biochemistry should be not be considered only as effects of increased temperature. Other factors have been reported as impacting on wine grapes biochemistry, such as increased atmospheric CO_2, increased radiation, improved viticultural techniques, and longer "hangtime" (Leeuwen and Darriet, 2016).

The grape flavour development has been found to be negatively affected by increasing seasonal temperature in the form of, for example, "***cooked flavours***" associated with overripe grapes (reviewed in Mozell and Thach 2014) and ***"petrol favours"*** in Riesling grapes (reviewed in Schultz, 2016). On a positive note, the increasing temperatures tend to depress pyrazine accumulation and enhance their degradation, resulting in a ***lower incidence of wines with "veggie, herbaceous notes"*** (reviewed in Mozell and Thach, 2014).

On the other hand, the abnormal decreases in temperature may ***reverse the ratio*** of sugar and ***acid concentrations in the favour of acids,*** which contributes to incomplete grape maturation, ***unripe flavours*** (reviewed in Mozell and Thach, 2014) and dry, ***more astringent,*** or even ***sour wines*** (reviewed in Brázdil *et al*., 2008). However, the decreases of temperature during night, measured by cool night index, may reduce carbon use by respiration and thus retain the carbon pool as molecular background for ***aroma and colour formation*** (reviewed in Schultz, 2016). Therefore, areas which are too cool (northern latitudes or higher altitudes) to support adequate ripening during the day have the benefits of cool nights. Oppositely, the areas where the temperature does not significantly decrease during night, such as in the southern latitudes or lower altitudes, may produce grapevines with low aroma content and red wines with a relatively light colour (Resco *et al.*, 2016). However, it is expected that areas in the Mediterranean Basin are expected to experience a significant increase in cool night index, which might affect the quality of wines produced in these areas (Malheiro *et al.*, 2010).

The elevation of CO_2 emission levels, with or without simultaneous shift in relative humidity, has similar effects on ***sugar-acid ratio*** as increasing temperature, and, additionally, contributes to ***increase in the level of tannins*** due to thicker skin development as an impact of faster growth. These two changes affect grape aroma and flavour. However, these effects are reversed in oak (*Quercus rubra*), which was reported to show a ***decrease in the concentration of ellagitannins***; this reduction may affect the overall quality wine barrel by lessening the tannins released into the finished wine (reviewed in Mozell and Thach, 2014).

Increased exposure to sunlight has been associated with ***inhibition of anthocyanin accumulation and acylation***, by excessively rising the grape berry temperature (Teixeira *et al.*, 2013; Bobeica *et al*., 2015), with further negative effects on ***red wine*** colour in particular. However, higher UV-B radiation in particular, has been reported as contributing to ***enhanced colour, flavonol, and tannin synthesis in red grapes*** (van Leeuwen and Darriet, 2016). In ***white cultivars***, prolonged exposure to high light and increased bunch temperature has been found as leading to excessive loss or ***degradation of aroma*** while concurrently ***total acidity is reduced*** because of excessive malic acid degradation, compromising wine microbiology stability and quality (Gatti *et al.*, 2015). Moreover, higher UV-B radiation in particular, has been reported as contributing to induction of ***off-flavours in white grapes***, such as o-Acetoaminophenone and 1,1,6-trimethyl-1,2-dihydronaphthalene (TDN) (van Leeuwen and Darriet, 2016). For the heavily affected high-altitude vineyards in particular, the detrimental impact of high radiation is limited by using ***adapted training systems or canopy management***. The exposure of grapes can be limited through reduced hedging and leaf pulling. ***Special nets that filter UV-B radiation*** have also been developed and can be used to protect the bunch zone (van Leeuwen and Darriet, 2016).

The occurrence of water stress has been reported to have negative effects on ***red grape*** colour by contributing to ***decrease in the ratio of di-/tri-hydroxylated anthocyanins*** (Bobeica *et al*., 2015). In ***white grapes***, water deficit contributes to ***decreased concentration of thiol***, an important flavour group for Riesling and Sauvignon blanc (reviewed in Schultz, 2016). On a more positive note, in Bordeaux wine region, it has been reported that average ***vintage quality*** has ***improved*** because of dryer production conditions. This may be because water deficit can improve quality potential for the production of ***red wine*** by inducing early cessation of shoot growth, reducing berry size, and enhancing skin phenolics in grapes. However, these results from the Bordeaux area cannot be replicated in dryer regions, where yield and quality may suffer from excessive water stress, in particular in soils with low water-holding capacity (van Leeuwen and Darriet, 2016).

The identified most commons decisions affected by the increase in temperature and sunlight relate to ***change in canopy management*** to provide additional shade so as to reduce sugars and increase acids (reviewed in Mozell and Thach, 2014). However, this is more suitable for white cultivars.

The most common identified decisions affected by the occurrence of water stress and water deficit relate to shallow tillage of the soil, which is known to limit the evaporation of soil water (Neethling *et al.*, 2016), and ***deficit irrigation strategies, such as partial root drying (RDI), sustained deficit irrigation (SDI), and regulated deficit irrigation (RDI) techniques***, which, at the same time, can contribute to optimal grape maturity and wine quality (reviewed in Mozell and Thach, 2014).

A more general decision suitable for all the negative impacts of climate change discussed in this section can be the ***grafting over or complete vineyard reinstallation to grape varieties more closely adaptable to the new climatic and weather conditions*** in order to produce grapes for premium wines (reviewed in Mozell and Thach, 2014). The positive impacts open opportunities to be identified and seized by grape farmers according to their specific needs.

The results of the cluster analysis indicated rather low values (between 0.10 and 0.24) and not statistically significant (average *P*-value 0.56) of the Pearson coefficient for the analysed correlations between the identified climate change impacts and associated critical decisions. The identified most relevant correlations were:

(a) between thiol concentration reduction, as an impact of occurrence of water stress, and decision to apply deficit irrigation techniques which can also contribute to optimal grape maturity and wine quality (Pearson coefficient 0.24);
(b) between the development of "petrol" flavour in white wines, as an impact of abnormal increase in diurnal seasonal temperature, and the decision to grafting over or complete vineyard reinstallation to grape varieties more closely adaptable to the new climatic and weather conditions in order to produce grapes for premium wines (Pearson coefficient 0.10).

On one hand, these correlations underline the weight of the increase in seasonal temperature and occurrence of water stress in terms of impacts on grape and wine quality. On the other hand, the low values of the Pearson coefficient for these correlations indicate that there may be other factors than the ones discussed above, which may have heavier impact on grape and wine quality, and associated decisions, and which need to be identified by grape farmers for efficient decisions in relation to impacts of climate change.

7.1.1.5. Grapevine pests and diseases

The most common identified climate change impacts on grape vine pests and diseases were related to increase in temperature and changes in air humidity (Table 7-5), and are further discussed, where possible, together with associated identified grape farmers' decisions.

Table 7-5. Climate change impacts on grapevine pests and diseases and critical decisions

Expected climate change	*Impacts*	*Critical decisions*
Increase in temperature + humid conditions	- ***Overall increase in pest and diseases' incidence;*** - ***Increased incidence of downy mildew;*** - ***Increased incidence of grey mould;*** - ***Increased incidence of fan leaf and leaf-roll associated viruses***	***- Adequate phytosanitary treatments;*** ***- Cultural practices;*** ***- Use of decision support tools***
Increase in temperature + dry conditions	- ***Overall decrease in pest and diseases' incidence (southern Europe);*** - ***Increased incidence of fan leaf and leaf-roll associated viruses***	***-Adequate phytosanitary treatments;*** ***- Cultural practices;*** ***- Use of decision support tools***
Increase in temperature+ reduced rainfall	- ***Increased European grapevine moth (central and eastern Europe);*** - ***Increased incidence of pests and diseases from warmer climate (northern Europe)***	***-Adequate phytosanitary treatments;*** ***-Cultural practices;*** ***-Use of decision support tools***

The increase in temperature has been associated with negative impacts when coupled with increased air humidity and with positive impacts when coupled with dry conditions. More specifically, in hotter climates, such as some of the Mediterranean countries (Portugal), where decreases in grape yields are expected, the ***pest incidence*** is also expected ***to decrease*** (reviewed in Ponti *et al*., 2018).

Among the diseases, downy mildew (*Plasmopara viticola*) was not reported in hot and dry climate regions, only in hot and humid climates. Grey mould (*Botrytis cinerea*), the third most damaging grapevine disease in Europe, can be found in similar climatic contexts. More dangerously, ***viruses (fan leaf and leaf roll-associated viruses)*** are projected to ***emerge*** in both types of climate and have mostly been reported in Mediterranean areas (Bois *et al*., 2017). However, all these diseases can be expected to emerge in the areas where there are expected changes in rainfall pattern (section 4.2.) and therefore, in the air humidity.

Noteworthy, the impacts of increasing temperature manifest differently across European wine regions. More precisely, the areas where the increase in temperature will not coincide with decrease in rainfall, such as central and Eastern Europe, may experience ***increasing risk of grapevine attack of downy mildew*** while areas with Mediterranean like climate conditions are much less prone to this risk (Malheiro *et al*., 2010). Among pests, in central and eastern Europe, the ***incidence of European grapevine moth (Lobesia botrana)*** is projected ***to increase*** across all vineyards of Hungary, Serbia, Moldova, Bulgaria, and Georgia (reviewed in Ponti *et al.*, 2018). Additionally, an increase in temperature, is expected to ***increase vineyards' susceptibility to powdery mildew disease*** (*Erysiphe necator*) (reviewed in Mozell and Thach, 2014). Powdery mildew was reported as most damaging disease in a larger range of temperature conditions with lower rainfall during the grape growing season (59 to 675 mm) (Bois *et al.*, 2017).

In northern European wine regions, such as Germany and neighbouring countries, the increase in temperature is expected to be associated with the ***occurrence of grapevine pests and pathogens originating from warmer climates.*** Some are already being detected increasingly in Palatinate or can be expected soon, such as the American grapevine leafhopper (*Erythroneura spp*.), or flavescence dorée disease (*Candidatus Phytoplasma vitis*), which has already been detected in western Switzerland (Koch and Oehl, 2018).

The most identified common decisions related to overall increased incidence of grapevine pests and diseases were, besides adequate ***phytosanitary treatments*** for each species and ***cultural practices (pruning, burning of infested organs, tillage and hoeing control soil-borne insects), the use of decision support tools***, such as vite.net (Rossi *et al.,* 2014) and MODEM_IVM DSS (Horta, 2012) for alerts on expected pests and diseases' emergence and more precise pest management.

7.1.1.6. Grape yield

The most common identified climate change impacts on grape yield were related to changes in temperature coupled with changes in rainfall, occurrence of drought and water stress, increased CO_2 levels, and late spring frost coupled with hail occurrence (Table 7-6), and are further discussed, where possible, together with associated identified grape farmers' decisions.

Table 7-6. Climate change impacts on grape yield and critical decisions

Expected climate change	***Impacts***	***Critical decisions***
Increase in temperature	- ***Increase in grape yield (northern and eastern Europe);*** - ***Decrease in grape yield (southern Europe)***	-
Decrease in temperature + wet conditions in spring	- ***Decrease in grape yield***	-
Increase in summer rainfall	- ***Increase in grape yield***	-
Prolonged drought + water stress	- ***Decrease in grape yield***	- ***Irrigation*** - ***Anti-transpirant treatments*** - ***Defoliation treatments***
Elevated CO_2 levels	- ***Increase in grape yield (in the long term)***	-
Late spring frost + hailstorm	- ***Decrease in grape yield***	-

The increase in temperature is expected to impact differently on grape yield across European wine regions. More specifically, the northern and eastern areas in particular, are expected to experience ***increases in grape yields*** (Neethling *et al.*, 2016; Fraga *et al.*, 2016), while southern areas with Mediterranean like climate conditions (e.g., Greece, Spain, Italy) are expected to face an overall ***decrease in grape yields*** (reviewed in Ponti *et al.*, 2018).

However, the levels of grape yields are expected to be highly variable, depending on local conditions (Iglesias *et al.*, 2010). More exactly, the yield increase may not be evident for the whole viticultural area at regional, or even country, level. For example, Heves County in Hungary, where an increase in summer temperature and a decrease in spring precipitation are forecasted, the ***grape yield*** is projected to ***decrease*** (Gaál *et al.*, 2014). Differently, in Germany, ***yield increases*** are expected over the entire grape growing area (Ponti *et al.,* 2018), were found to have detrimental to grapevine productivity in Galicia. However, it is expected that increased rainfall during summer may contribute to increased grape yield (Lorenzo *et al.*, 2013).

The occurrence of prolonged drought and water stress has been observed and reported to critically ***reduce the grape yields*** in parts of south-eastern Europe (Vršič and Vodovnik, 2012) and is expected to have similar impacts in the Mediterranean areas, such as southern Iberia (Extremadura and La Mancha in Spain and Alentejo and Douro in Portugal), Emilia Romagna and Lombardy in Italy and along the Aegean Sea (Malheiro *et al.*, 2010; Fraga *et al.*, 2016;

Fraga and Santos, 2017).

The projected increase in CO_2 atmospheric levels has been calculated to have a significant positive effect on grape yield (reviewed in Schultz, 2016). However, it is projected that high CO_2 in field conditions will have no major effect on single ***berry weight*** in the short term, but might ***increase it in the long term*** due to a cumulative effect (INRA, 2016).

The occurrence of late spring frost and hailstorms, most common in the northern European wine regions (Resco *et al.*, 2016), have been found to ***critically affect the grapevine productivity*** (reviewed in Brázdil *et al.*, 2008).

The most common identified decisions were related to impacts of drought and water stress. As some parts of southern Europe are projected to become very dry (e.g. southern Iberia, Italy and southeastern Balkan Peninsula), ***irrigation*** of vineyards is expected to become necessary in order to maintain wine yield and quality at current levels (Malheiro *et al.*, 2010). However, the use of other practices, such as ***anti-transpirant combined with defoliation treatments***, to alter water regime in the grapevine, are expected to contribute to yield reduction for some grape varieties (e.g. Nebbiolo) (INRA, 2016). However, this could be due to genetic characteristics as well as other cultural practices.

7.2. Findings from the focus group discussions in Douro viticultural region

In this sub-chapter, there are presented the common and different grape farming decisions affected by climatic changes, as identified through the focus group discussions held in Douro wine region, with local representative stakeholders for grape-wine sector (RD4) as well as through the systematic literature review. Noteworthy, the findings of the literature review indicate decisions identified through climate scenarios, long term projections, analysis of historical data, as well as through observational data. The findings of the focus group discussions indicate decisions mainly affected by the availability of seasonal and decadal forecasts. Therefore, the overall findings from the two sources should be interpreted accordingly.

7.2.1. Key farming decisions

In the next two sections, there are presented the common and different key farming decisions as indicated by the findings of the focus group discussions and of the systematic literature review. However, these decisions are not discussed here, because they are already detailed in the referred sections or documents.

7.2.1.1. Findings common to the literature review

The common key farming decisions identified through literature review and focus group discussions were mainly affected by the changes in temperature, and to lesser extent by sunlight, as illustrated in Table 7-7.

Table 7-7 Common key grape farming decisions identified through focus group discussions and literature review

TEMPERATURE				SUNLIGHT			
Literature review		Focus group discussions		Literature review		Focus group discussions	
Climate changes	***Decisions***	**Climate changes**	***Decisions***	**Climate changes**	***Decisions***	**Climate changes**	***Decisions***
Increase in temperature	*Adjusted training techniques and row orientation*	Temperature	*Vineyard installation*	Increased sunlight	*Adapting the training system*	Exposure to sunlight	*Vineyard installation*
	Use of warm climate clones		*Training system*	-	-	-	-
	Introduction of new varieties		*Choice of varieties*	-	-	-	-
	Late-ripening clones		*Choice of rootstock*	-	-	-	-
	Grafting over more adaptable grape varieties	-	-	-	-	-	-
	Rootstocks with longer cycle and late ripening clones	-	-	-	-	-	-

In relation to temperature, the ***findings from the focus group discussions*** indicated ***vineyard installation, training system, the choice of grape varieties and rootstock*** as the critical decisions affected by temperature, as discussed in sections 3.2.1.1., 3.2.1.2., 3.2.2.2., 3.2.2.3., and 3.2.3.1. of deliverable D 3.1. (RD4). The ***findings from the literature review*** indicated ***vineyard design, and choice of clones, varieties, and rootstock*** as being mainly affected by increased temperature, as discussed in sections 7.1.1.1., 7.1.1.2., 7.1.1.4., and 7.1.1.5. However, during the focus group discussions the choice of rootstock has been argued to be more influenced by the type of soil rather than by weather variables, such as temperature.

The sunlight has been identified to impact mainly on decisions regarding ***choice of grape varieties*** as identified through ***focus group discussions*** (section 3.2.1.1., RD4) and through ***literature review*** (section 7.1.1.4.).

The findings from the literature review were identified for different European wine regions, while the ones from the focus group discussions were identified in a wine region with Mediterranean like climate conditions. However, as indicated by these common findings, these decisions may be suitable across different European wine regions, all other factors being considered equal.

7.2.1.2. Additional findings to the literature review

The different key farming decisions identified through literature review and focus group discussions were mainly affected by the changes in temperature, carbon dioxide level, rainfall, salinity and sunlight, as well as occurrence of drought and water stress, with rainfall being prevalent for the findings from the focus group discussions and temperature – for the findings from the literature review, as illustrated in Table 7-8. Due to very low numbers, the decisions affected by the changes in soil salinity and sunlight were not included in the table, but they are presented in text as "other decisions".

In relation to changes in temperature, the most common identified decisions through the ***literature review*** were related to ***vineyard settlement, canopy management, choice of rootstock, phytosanitary treatments, cultural practices, and use of decision support tools***, as discussed in sections 7.1.1.1., 7.1.1.2., 7.1.1.4., and 7.1.1.5. The findings from the ***focus group discussions*** indicated ***canopy management and adaptation of training system*** as the most common decisions affected by the mild temperature coupled with high air humidity, as discussed in section 3.2.2.3. of deliverable D 3.1. (RD4).

The elevated carbon dioxide levels were identified only through ***literature review*** as a factor impacting, when coupled with dry conditions, on decisions related to ***irrigation, adjusted trellis' height, management of soil conditions, use of grape resistant varieties, introduction of winter crops***, and (sections 7.1.1.1.,7.1.1.4., and 7.1.1.6.), and, when coupled with increased temperature, on decisions relating to ***early leaf removal and irrigation*** (section 7.1.1.3.).

The most common ***reviewed*** decisions affected by the occurrence of drought and water stress were related to ***shallow tillage, irrigation techniques, switching to more adaptable grape varieties, anti-transpirant and defoliation treatments***, as discussed in sections 7.1.1.4. and 7.1.1.6. The findings from the ***focus group discussions*** indicate i***rrigation*** as the most common decision affected by the occurrence of water stress, as discussed in section 4 of deliverable D 3.1. (RD4).

In relation to rainfall, the most common critical decisions which were identified during the ***focus group discussions*** were related to ***vineyard installation, choice of grape varieties, assessing the degree of grape ripeness, and setting the harvest date***, as discussed in sections 3.2.1.1., 3.2.1.2., and 3.2.3.1. of deliverable 3.1. (RD4). Differently, through ***literature review***, it was identified that a decrease in summer rainfall coupled with the occurrence of drought determined early ripening and mostly impacted on the decisions related to ***balancing the vine load as to delay the onset of grape maturation***, as discussed in section 7.1.1.3.

The increased solar radiation, and increased exposure to it, mostly impacted on decisions relating to ***canopy management,*** as identified through ***literature review*** (section 7.1.1.4.), and to decisions related to ***vineyard installation and choice of grape varieties***, as identified during the ***focus group discussions*** (sections 3.2.1.1. and 3.2.1.2. of deliverable D 3.1. (RD4).

Other decisions were affected by increased soil salinity and related to ***irrigation,*** as identified through ***literature review*** (section 7.1.1.3.), and by windiness and related to the ***training system*** (section 3.2.2.2. of RD4).

Table 7-8 Different key grape farming decisions identified through focus group discussions and literature review

TEMPERATURE				CARBON DIOXIDE				DROUGHT AND WATER STRESS				RAINFALL			
Literature review		**Focus group discussions**		**Literature review**		**Focus group discussions**		**Literature review**		**Focus group discussions**		**Literature review**		**Focus group discussions**	
Climate changes	***Decisions***	**Climate changes**	***Decisions***	**Climate changes**	*Decisions*	-	-	**Climate changes**	***Decisions***	**Climate changes**	***Decisions***	**Climate changes**	*Decisions*	**Climate changes**	***Decisions***
Increase in temperature	*Settling the grapevine plantation at thermally suitable altitude on hillsides*	-	-	Increase in CO2 atmospheric concentration + dry conditions	*Irrigation*	-	-	Occurrence of water stress	*Shallow tillage*	-	-	Decrease in summer rain+ drought	*Increase vine load*	Rainfall	*Vineyard installation*
	Early leaf removal	-	-		*Adjusted trellis' height*	-	-		*Deficit Irrigation techniques*	Water stress	*Irrigation*	-	-		*Choice of grape varieties*
	Late leaf removal	-	-		*Management of soil conditions*	-	-		*Grafting over more adaptable grape varieties*	-	-	-	-		*Assessing the desired degree of ripeness by physico-chemical analysis*
	Use of rootstocks with longer cycle	-	-		*Use of drought resistant varieties*	-	-	Prolonged drought + water stress	*Irrigation*	-	-	-	-		*Setting the harvest date*
	Use of late-ripening clones	-	-		*Introduction of winter cover*	-	-		*Anti-transpirant treatments*	-	-	-	-	-	-

					crops										
	Adapting training system	-	-		*Early leaf removal*	-	-		*Defoliation treatments*	-	-	-	-	-	-
Increase in temperature + elevated CO_2 level+ drought	*Use of drought resistant rootstocks*	-	-		*Irrigation*	-	-		-	-	-	-	-	-	-
Increase in temperature + humid conditions	*Adequate phytosanitary treatments*	Mild temperature+ high air humidity	*canopy management (aeration)*	-	-	-	-		-	-	-	-	-	-	-
	Cultural practices		*training system*	-	-	-	-	-	-	-	-	-	-	-	-

7.2.2. Key socio-economic decisions

In this section, there are briefly presented the key socio-economic decisions as indicated by the findings from the focus group discussions (Table 7-9). These decisions were affected by a combination of climatic and economic drivers, and are detailed in the referred source (RD4).

Table 7-9. Key grape farmers' socio-economic decisions identified through focus group discussions

Driver	*Socio-economic decision*
Climatic conditions	***Ordering young plants of new varieties from nurseries;***
	Less costly use of manpower/machinery for interventions on grapevines;
	Labour management for harvest operations;
	Negotiation of contracts on manpower and machinery for wine making operations;
	Planning stock management;
	Repeated phytosanitary treatments (and associated costs)
Consumer preferences	***Choice of grape varieties***
Availability of manpower	***Planning harvest operations***

The climatic conditions impacted on decisions relating to ordering young plants of new grape varieties from nurseries, use of manpower and machinery for grapevine maintenance, labour management during harvest and processing, and, indirectly, on planning and maintenance of stocks (table 7-9).

The decisions relating to ***new grape varieties*** had to be made taking into consideration that these clones needed to have certain genetic characteristics, such as heat tolerance, among others, as discussed in section 4 of deliverable D 3.1. (RD4).

The decisions relating to the ***use of manpower and machinery*** for performing interventions on grapevines throughout the vegetative cycle, represent a major cost in the production of wine because of the need to intensively use both for very specific periods of time, as discussed in section 3.2.2.2. of deliverable D 3.1. (RD4).

The decisions relating to ***labour management during harvest*** and processing should allow efficient and timely management of staff, both internal and subcontracted, and better negotiation of contracts, both of manpower and machinery, and guarantee the availability of required labour in the right moments, as discussed in section 4 of deliverable D 3.1. (RD4). Emerging from this, the availability of manpower directly impacts the planning of harvest operations.

The ***planning and maintenance of stocks*** (e.g. fertilizers, trellis wires, pesticides, processing aids or additives for musts and wines, and yeasts) to supply grape and wine production processes, as being affected by the climatic conditions, translates into concerns over cost efficiency and represents an indirect but important consequence of climate impacts, as discussed in section 3.2.4. of deliverable RD 3.1. (RD4).

The occurrence of rainfall impacted on the durability effect of ***phytosantary treatments***. More precisely, 25 mm of rain occurring after a treatment makes necessary the repetition of the treatment and associated costs, as discussed in section 3.2.2.3. of deliverable D 3.1. (RD4).

Consumer preferences for certain types of wine (white, rosé or red) have been identified as impacting on the ***choice of grape varieties***, in the context of changing climatic conditions posing at risk the possibility to produce the wines suiting these preferences, as discussed in section 3.2.1.2. of deliverable D 3.1. (RD4).

7.2.3. Climate information needs

In this section, the findings presented in Table 7-10 indicate the climate information needs identified during the focus group discussions and are briefly discussed below per type of decision. These findings are discussed in more detail in deliverable 3.1. (RD4).

Table 7-10. Types of decisions and associated climate information needs for grape farmers

Type of decision	***Decision***	***Needed type of information***	**Reliability of the needed type of information**
Long-term	- ***Choice of region and site for establishment of new vineyards***	- ***Decadal forecast***	80 %
Long-term	- ***Choice of grape varieties***	- ***Decadal forecast***	80 %
Medium to long	- ***Choice of grapevine rootstock and clones***	- ***Seasonal forecast;*** - ***Decadal forecast***	70 % 80 %
Medium to long	- ***Definition of training and pruning system***	- ***Seasonal forecast;*** - ***Decadal forecast***	70 % 80 %
Short-term	- ***Pest management***	- ***Seasonal forecast***	70 %
Short-term	- ***Maturation control planning;*** - ***Setting harvest dates***	- ***Seasonal forecast***	70 %
Short-term	- ***Stock management (products and consumables for viticulture and winemaking)***	- ***Seasonal forecast***	70 %

For the ***choice of region and site for establishment of new vineyards***, which is a long-term decision, the ***decadal forecasts,*** with quarterly resolution and a reliability of 80 % were identified as critical information needs. More specifically, the trend of climate change in relation to temperature and precipitation, as well as the local trend of water availability were of particular importance. However, for this decision, there were indicated additional influencing factors, such as soil type, fertility and health status, slope, and sun exposure, as discussed in section 3.2.1.1. of RD4.

For the ***choices of grapes varieties*** for planting, another long-term decision, the ***decadal forecasts***, with quarterly resolution and a reliability of 80 % were identified as critical information needs. Additionally, the magnitude of variation of the change in temperature was indicated as a particular climate information need, as discussed in section 4 of RD4. However, for this decision, there were indicated additional influencing factors, such as soil, sun exposure, altitude, and consumers' preferences for certain types of wines (section 4 of RD4).

For the ***choice of grapevine rootstock and clones*** for planting, ***6-month lead-time seasonal forecasts***, with weekly resolution and a minimum reliability of 70% and decadal forecasts, with quarterly resolution and a reliability of 80 %, were identified as critical information needs. However, it has been argued that the choice of rootstocks is more influenced by the type of soil and its characteristics rather than by climatic conditions, as discussed in section 3.2.1.2. of RD4.

For the ***definition of training and pruning system***, ***6-month lead-time seasonal forecasts***, with weekly resolution and a minimum reliability of 70% and decadal forecasts, with quarterly resolution and a reliability of 80 %, were identified as critical information needs. However, for the choice of training system, there were indicated additional influencing factors, such as solar radiation, wind, temperature and water capacity of the soil, as discussed in sections 3.2.2.2. and 4 of RD4.

For ***effective pest management***, ***6-month lead-time seasonal forecasts***, with weekly resolution and a minimum reliability of 70%, was identified as critical information need. However, for this intervention, additional factors such as the cultural practices (adapted training systems, canopy management to allow plant aeration, increased soil drainage in the proximity of vines) and phytosanitary treatments have been identified as having great influence. Nevertheless, having access to seasonal climate forecasts is an important economic gain derived from anticipating and managing treatments in the vineyard and more efficient manpower management, as discussed in section 3.2.2.3. of RD4.

For ***maturation control planning and setting harvest dates***, ***6-month lead-time seasonal forecasts***, with weekly resolution and a minimum reliability of 70% was identified as critical information need. More specifically, in the days preceding harvest, temperature variation and occurrence of rainfall may influence the composition of the must and the sanitary quality of the grapes, with consequences on the harvest time, as discussed in section 3.2.3.1. of RD4. However, for this decision, there were indicated additional influencing factors, such as the results of physicochemical analysis of sugars, organic acids, polyphenols and aromatic precursors, as well as the availability of manpower section 3.2.3.1. of RD4.

For ***stock management*** (products and consumables for viticulture and winemaking), ***6-month lead-time seasonal forecasts***, with weekly resolution and a minimum reliability of 70% and decadal forecasts were identified as critical information needs, as discussed in section 4 of RD4.

To conclude with, the importance of having access to the climatic information discussed above and the associated gains discussed in section 7.3 of this document and in R4 indicate climatic drivers as greatly impacting on grape and wine production. However, the additional factors identified during the focus group discussions, as discussed in this section, indicate that climatic drivers should not be considered in isolation when analysing the decisions of grape farmers.

8. VULNERABILITY OF *DURUM WHEAT-PASTA* SECTOR TO CLIMATE VARIABILITY AND CHANGE

8.1. Findings from the literature review

In this sub-chapter, there are presented the most common identified climatic changes and related negative and positive impacts on durum wheat crop, as well as the farming decisions relating to these impacts.

Noteworthy, all the tables in this section are presented with alternative shaded and blank areas, to enhance horizontal visualisation for similar types of climate change impacts and decisions.

8.1.1. Climate change impacts, and critical decisions, on European durum wheat cultivation

The most common identified impacts were on durum wheat cultivation areas, varieties, plant development, and yield.

Noteworthy, these impacts were mostly assessed through modelling and projecting work, unless otherwise stated in text.

8.1.1.1. Cultivation areas

The most common identified climatic changes were related to increase and decrease in rainfall which mainly impacted on changes in suitability of durum wheat cultivation areas, as illustrated in Table 8-1.

Table 8-1 Climate change impacts on durum wheat cultivation areas and critical decisions

Expected climate change	*Impact*	*Critical decision*
Decrease in rainfall	***Decreased suitability of cultivation areas***	***Decrease in cultivation areas***
Increase in rainfall	***Increased suitability of cultivation areas***	***Increase in cultivation areas***

More precisely, it is expected a reduction in summer and autumn rainfall in southern Europe, which will mainly impact on durum wheat cultivation areas in terms of their ***reduced suitability.*** This is very likely because durum wheat is cultivated predominantly in the Mediterranean Basin, in areas with relatively low and uncertain rainfall, and therefore reduced water availability for durum wheat production, which is exposed to severe water deficit (INRA, 2015; Rothamstead Research, 2009). Additionally, the Mediterranean Basin faces cumulative, unevenly distributed and increasingly severe impacts of other climatic changes, as discussed in section 5, which may further decrease the suitability of durum wheat cultivation areas.

All these factors may result in the ***reduction of the durum wheat cultivation areas***, such as in one part of Andalusia, where the farmers decided to converted their rainfed durum wheat crops into irrigated olive groves, due to decrease in annual rainfall (Ronchail *et al.,* 2014).

However, in the areas where, under B1 scenario (temperature increased all year around by at least 1 °C to 2 °C), the cumulated rainfall is expected to increase all year around, such as in some Mediterranean coastal areas under Atlantic influence (e.g. Portugal and Western Spain), or in the areas where rainfall is expected to increase only during summer, such as in those under Mediterranean influence, with ***increased suitability***, the durum wheat farmers are expected to ***increase the cultivation areas*** as an adapting practice (Leclère *et al.*, 2013).

8.1.1.2. Durum wheat varieties

The occurrence of drought and water deficit were the most common identified climatic drivers impacting on durum wheat varieties in terms of their response to the stress conditions, as illustrated in Table 8-2.

Table 8-2 Climate change impacts on durum wheat varieties and critical decisions

Expected climate change	***Impact***	**Critical decision**
Occurrence of drought	***Reduced leaf elongation rate***	***Use of drought resistant cultivars***
Occurrence of water deficit at flowering time	***Reduced agronomic output***	

More specifically, under drought and water stress conditions, the more sensitive durum wheat varieties may respond in the form of ***reduced leaf elongation rate*** compared to the less sensitive ones, which may further translate into similar differences in terms of ***agronomic output,*** particularly if water deficit occurs at flowering time (INRA, 2015). In such instances, which are rather common across the Mediterranean durum wheat cultivation areas (section 5), the farmers decided to use ***drought resistant cultivars*** (Københavns Universitet, 2013).

8.1.1.3. Plant development and phenology

The increase in temperature was the most common identified climate change impacting on durum wheat plant development and phenology, as illustrated in Table 8-3. The different impacts are further discussed, where possible, together with associated decisions.

Table 8-3 Climate change impacts on durum wheat development and phenology and critical decisions

Expected climate change	***Impact***	***Critical decision***
Increase in temperature	- ***Reduction in phenological cycle duration***	- ***Irrigation;*** - ***Fertilization***
Increase in temperature+ soil moisture deficit	- ***Occurrence of "shrivelling"***	- ***Use of drought resistant varieties;*** - ***Irrigation;*** - ***Crop insurance***
Increase in temperature during winter	- ***Reduced cold stress;*** - ***Reduced vernalization phase***	-

More specifically, the increased temperatures have been reported to contribute to accelerated development of durum wheat plants and to shorter growth stages during which the photosynthetic products are absorbed, ultimately affecting the overall plant productivity (Sima *et al.*, 2015). As such, findings from southern Italy (Apulia region) indicated that higher temperatures induced an overall ***reduction in the duration of the phenological cycle*** of winter durum wheat. This reduction was higher in the vegetative cycle (i.e. sowing-anthesis phase: up to - 30 days), whereas in the reproductive cycle (i.e. anthesis-maturity phase) reduction was negligible (up to – 3-4 days). Therefore, the farmers are expected to to ensure optimum water (***irrigation***) and nutrients levels (***fertilization***) throughout all phenological stages, to obtain optimum levels of agronomic output, despite the reduced overall phenological cycle (Ventrella *et al.*, 2012).

In south-eastern Europe, increases of summer temperature above 30^{0}C for several days in the row, coupled with soil moisture deficit, were reported to have negatively influenced durum wheat plant metabolism, producing the "***shrivelling***" phenomena, which is highly detrimental to overall plant development. In such situations, the small farmers started to use ***drought resistant varieties***, while the big farmers ensured adequate ***irrigation*** conditions and ***insured their crops*** against extreme climatic events such as prolonged droughts (Sima *et al.*, 2015).

However, in the European durum wheat growing areas where the projected increase in temperature is expected during winter, this might have both positive and negative effects on durum wheat plants, depending on their development stages. More precisely, warmer winters are likely to be beneficial (***reduced cold stress*** on durum wheat seedlings), but rather ***detrimental during the vernalization phase*** (the period of cooler growing conditions necessary for winter durum wheat to develop the reproductive growth) (Sima *et al.*, 2015).

8.1.1.4. Durum wheat yield

The most common identified climate change impacts on durum wheat yield were related to occurrence of heat stress and drought, changes in temperature coupled with changes in rainfall, and increase in atmospheric CO_2 levels (Table 8-4), and are further discussed, where possible, together with associated identified durum wheat farmers' decisions.

Table 8-4 Climate change impacts on durum wheat yield and critical decisions

Expected climate change	***Impact***	***Critical decision***
Occurrence of heat stress + variable genetic potential	***Variable yield***	- ***Crop insurance***
Occurrence of drought	***Decrease in yield***	- ***Use of drought resistant varieties;*** - ***Irrigation;*** - ***Crop insurance***
Uneven increase in temperature + variable rainfall pattern	***Variable yield***	- ***Supplemental irrigation;*** - ***Crop insurance;*** - ***Improve soil moisture retention capacity;*** - ***Shift crops from vulnerable areas;*** - ***Shift in sowing date***
Increase in atmospheric CO_2 concentration + no decrease in rainfall	***Increase in yield***	- ***Irrigation (if there is decrease in rainfall)***

In southern Europe, where most of durum wheat is grown, there has been reported an overall ***downward trend for the durum wheat yield,*** because under increasingly warmer conditions, the general decrease in durum wheat productivity is caused by a shortening of the growing period, with subsequent negative effects on grain filling (Iglesias *et al.*, 2012). The yield decrease varies with the different factors and location, as further discussed.

More specifically, across the most important durum wheat growing regions in the Mediterranean Basin, namely Andalusia (Southern Spain, S-Spain), Midi-Pyrenees (Southern France, S-France), Central districts (France, N-France), Tuscany (Central Italy, C-Italy), Apulia (Southern Italy, S-Italy), Central Macedonia (N-Greece) and South Aegean (Greece, S-Greece), the projected ***yield*** is expected to ***variably decrease*** under heat stress conditions for durum wheat varieties with different lengths of growth cycle, namely Svevo (short cycle), Saragolla (medium cycle) and Levante (long cycle). Among the three, the variety with a longer cycle, Levante, is expected to show the highest decrease (-6.2 %), while the one with a shorter cycle, Svevo, the lowest (-4.7 %). However, at a regional scale, the highest decrease can be expected in Spain (-8.9 % on average) and S-Greece (-5.1 %), whereas this effect can be less evident in the other regions (-3 %). In such situations, durum wheat farmers are expected to ***insure their crops*** (Moriondo *et al*., 2016).

The occurrence of drought for several years in the row has been reported to have contributed to ***decrease in durum wheat yields*** in parts of Italy and Spain, which, in return, contributed to increase in market prices (Musolino *et al*., 2018). However, the price increases were not proportional with the yield decreases. In Italy, the yield decreased by -9.9 % and the price increased by +3.1 % between 2005 and 2007. In Spain, the yield decreased by -2 % and the price increased by +34.4 % between 2005 and 2008. These examples indicate that both climatic variability and market price volatility are important factors to consider in terms of their impacts on durum wheat production. Other findings, from south-eastern Europe, indicated up to 65 % decrease in durum wheat yield as an impact of annual drought occurrence, when farmers decided for ***use of drought resistant varieties***, depending on their resources (Sima *et al.*, 2015).

A projected uneven increase in temperature, coupled with highly variable rainfall pattern, in the long term, across the Mediterranean durum wheat growing areas, is expected to impact on ***increased*** regional ***variability of durum wheat yields.*** In this context, there can be expected a number of adaptation measures to reduce yield variability, such as ***supplemental irrigation, crop insurance, improve soil moisture retention capacity,*** and ***shift crops from vulnerable areas*** (Gonzalez-Zeas *et al*., 2014). Other findings from the same areas reported that, under expected similar conditions associated with similar changes in durum wheat yield, the adaptation measures are expected to include ***supplemental nitrogen fertiliser, supplemental irrigation, and shift in sowing date*** (Iglesias *et al.*, 2012).

Across the same regions, the projected increase in CO_2 atmospheric concentration is expected to contribute to an ***increase in durum wheat yield***, but only in the areas where there is no simultaneous decrease in rainfall (Blanco *et al.*, 2017). However, such increase has been long questioned, as discussed in section 4.3. In the wider context, the durum wheat growing areas, stretched across the Mediterranean Basin, are characterized by decreased summer rainfall and increasing variability of annual precipitation, as discussed in section 5, which, together with increased tropospheric O_3 concentration, can reduce the increasing effect of CO_2 on durum wheat yields (section 4.3.). In the areas with decreased and erratic rainfall, durum wheat farmers may decide for irrigation, provided the water availability is not an issue.

8.2. Findings from the workshops in Ravenna, Italy

In this sub-chapter, there are presented the common and different durum wheat farming decisions affected by climatic changes, as identified through the two scoping workshops held in Ravenna region, with representative stakeholders from different Italian durum wheat regions, as well as through the systematic literature review. It is important to note, however, that overall, decisions identified through the literature review are mostly affected by information derived from climate scenarios and decadal predictions, whereas the decisions identified through the scoping workshop are more affected by the availability of seasonal and decadal forecasts. Therefore the overall findings from the two sources should be interpreted accordingly.

8.2.1. Key farming decisions

In the next two sections, there are presented the common and different key farming decisions as indicated by the findings of the workshops and of the systematic literature review. However, these decisions are not discussed here, because they are already detailed in the referred sections or documents.

8.2.1.1. Findings common to the literature review

The common findings identified through the ***workshops and literature review*** mostly related to the ***choice of durum wheat varieties*** as affected by the increase in temperature, as discussed in section 8.1.1.3. of this report and section 3.2.2.2. of deliverable D 4.1.

8.2.1.2. Additional findings to the literature review

The different key farming decisions identified through literature review and workshops were mainly affected by changes in temperature and rainfall, with rainfall being prevalent for the findings from the workshops and temperature – for the findings from the literature review, as illustrated in Table 8-5. Other less impacting changes and associated decisions are illustrated under "Others" and include findings from the literature review relating to occurrence of drought, water deficit, and heat stress, and changes in the atmospheric CO_2 concentration, as well as findings from the workshops relating to the occurrence of heatwaves, solar radiation and wind speed.

In relation to changes in temperature, the most common identified decisions through the ***literature review*** were related to the increase in temperature across the durum wheat growing areas which may impact on decisions relating to ***irrigation, improvement of soil moisture retention capacity, and shift in crops in more vulnerable areas***, so as to maintain and improve the plant development and yield affected by this change, as discussed in sections 8.1.1.3. and 8.1.1.4. The findings from the ***workshops*** indicated that temperature may impact on ***phytosanitary treatments, fertilisation planning, and breeding activities, soil labouring, and setting of sowing and harvest time,*** as discussed in sections 3.2.1. and 3.2.2.2. of deliverable D 4.1. (RD2).

In relation to changes in rainfall, the findings from the ***literature review*** indicated the decisions relating to the ***durum wheat cultivation areas*** as most affected by these changes, as discussed in section 8.1.1.1. The findings from the ***workshops*** were ***similar to the ones relating to the decisions affected by temperature***, with an additional one relating to ***weed management,*** as discussed in sections 3.2.1. and 3.2.2.2. of deliverable D 4.1. (RD2).

Other different findings from the ***literature review*** indicated the occurrence of drought and water deficit, as well as an increase in atmospheric CO_2 concentration, as mainly impacting on decisions relating to ***irrigation and the use of drought resistant cultivars***, as discussed in sections 8.1.1.2. and 8.1.1.4.

Other different findings from the ***workshops*** indicated that the occurrence of heatwaves can majorly impact on ***phytosanitary treatments, fertilisation and breeding activities,*** whereas the solar radiation and wind speed can majorly impact on the ***choice of variety, and setting the sowing and harvest time,*** as discussed in sections 3.2.1. and 3.2.2.2. of deliverable D 4.1. (RD2).

Table 8-5 Different key durum wheat farming decisions identified through workshops and literature review

TEMPERATURE				RAINFALL				OTHERS			
Literature review		Workshops		Literature review		Workshops		Literature review		Workshops	
Climate changes	***Decisions***	**Climate changes**	***Decisions***	**Climate changes**	***Decisions***	**Climate changes**	*Decisions*	**Climate changes**	*Decisions*	**Climate changes**	***Decisions***
Increase in temperature	*Irrigation*	Temperature	*Phytosanitary treatments*	Decrease in rainfall	*Decrease in cultivation areas*	Rainfall	*Phytosanitary treatments*	Occurrence of drought	*Use of drought resistant varieties*	Occurrence of heatwaves	*Phytosanitary treatments*
			Fertilisation planning	Increase in rainfall	*Increase in cultivation areas*		*Fertilisation planning*		*Irrigation*		*Fertilisation*
Uneven increase in temperature + variable rainfall pattern	*Supplemental irrigation*		*Breeding and genetic improvement*	-	-		*Breeding and genetic improvement*	Occurrence of water deficit at flowering time	*Use of drought resistant cultivars*		*Breeding and genetic improvement*
	Improve soil moisture retention capacity	Near soil surface temperature	*Soil labouring before sowing*	-	-		*Soil labouring before sowing*	Increase in atmospheric CO_2 concentration + no decrease in rainfall	*Irrigation (if there is decrease in rainfall)*	Solar radiation; Wind speed	*Choice of variety*
	Shift crops from vulnerable areas			-	-		*Choice of variety*	-	-		*Sowing timing*
-	*Shift in sowing date*		*Sowing timing*	-	-		*Sowing timing*	-	-		*Harvest timing and planning*
-	-		*Harvest timing and planning*	-	-		*Harvest timing and planning*	-	-	-	-
-	-	-	-	-	-		*Weed management*	-	-	-	-

8.2.2. Key socio-economic decisions

In the next two sections, there are presented the key socio-economic decisions as indicated by the findings from the literature review and from the scoping workshops (Table 8-6). However, these decisions are not discussed in detail in these sections, because they are detailed in the referred sections or documents.

Table 8-6 Key durum wheat farmers' socio-economic decisions identified through literature review and scoping workshops

<table>
<tr><th colspan="2">Literature review</th><th colspan="2">Workshops</th></tr>
<tr><th>Driver</th><th>Decisions</th><th>Driver</th><th>Decisions</th></tr>
<tr><td>Increase in temperature + soil moisture deficit</td><td rowspan="4">Crop insurance</td><td>Temperature</td><td rowspan="3">Planning the supply chain contracts</td></tr>
<tr><td>Occurrence of heat stress + variable genetic potential</td><td>Rainfall</td></tr>
<tr><td>Occurrence of drought</td><td>Occurrence of heatwaves</td></tr>
<tr><td>Uneven increase in temperature + variable rainfall pattern</td><td>-</td><td>-</td></tr>
</table>

8.2.2.1. Findings from the literature review

The most common socio-economic decisions identified through the ***literature review*** related to ***insuring the durum wheat crops*** against the risks posed by the increase in temperature coupled with soil moisture deficit, occurrence of prolonged drought and heat stress, and uneven increase in temperature combined with variable rainfall pattern across different durum wheat growing areas, as already discussed in sections 8.1.1.3. and 8.1.1.4.

8.2.2.2. Findings from the scoping workshops

Differently, the most common socio-economic decisions identified through the ***scoping workshops*** related to ***planning the supply chain contracts***, as discussed in section 3.2.1. of deliverable D 4.1. (RD2).

8.2.3. Climate information needs

In this section, the findings presented in Table 8-7 indicate the climate information needs identified during the scoping workshops. These findings are discussed in more detail in sections 3.2.1. and 3.2.2.3. of deliverable 4.1. (RD2).

Table 8-7 Types of decisions and associated climate information needs for durum wheat farmers

Type of decision	Decision	Needed type of information
Long-term	- ***Monitoring emergence of new pests/diseases/weeds***	***Decadal forecast***
Long-term	- ***Equipment purchase***	***Decadal forecast***
Medium to long	- ***Choice of varieties***	***Decadal forecast***
Short-term	- ***Setting the harvest time***	***Seasonal forecast***
Short-term	- ***Selection of sowing density***	***Seasonal forecast***
Short-term	- ***Fertilisation***	***Seasonal forecast***
Short-term	- ***Pests/disease management***	***Monthly forecast***
Short-term	- ***Weed management***	***Monthly forecast***

The most required ***seasonal climate information*** was related to humidity, temperature and precipitation, water balance and wind. This information is mostly useful for all the decision to be taken between October and July, in relation to ***fertilisation, selection of seed density at sowing, and the setting of harvesting time.***

Monthly forecasts were identified to be most useful for decisions related to ***pests, diseases and weeds' management***.

Additionally, there was recorded the interest for global forecasts, identifying areas at risk in the major world durum wheat producing regions, because climatic risks are known as drivers of durum wheat market prices.

9. COMMON CRITICAL DECISIONS TO ALL THE THREE SECTORS

In the following two sections, there are presented only the climatic changes and critical farming decisions common across the three sectors. However, they are not discussed here, as they are already presented in the relevant sections.

Noteworthy, all the tables in this section are presented with alternative shaded and blank areas, to enhance horizontal visualisation for similar types of climate change impacts and decisions.

9.1. From the literature review

The findings from the systematic review indicated the changes in temperature, and occurrence of drought, water stress and water deficit as common drivers of the decisions made by producers across olives, grapes and durum wheat sectors, as illustrated in Table 9-1. In the table, the decisions are presented as groups of similar decisions.

More specifically, the groups of decisions most affected by the ***increase in temperature*** were related, in the order of importance, to the ***use of varieties with genetic resistance to warmer conditions***, followed by ***irrigation techniques, canopy management, and plantation settlement*** across the three sectors.

The critical decisions affected by the ***occurrence of drought, water stress and water deficit*** were related to ***water stress reducing measures (careful control of weeds, low plant density, adequate intensity of pruning/training), irrigation techniques, canopy management, and use of more adaptable varieties.***

Table 9-1 Common climate change impacts and critical decisions identified through literature review across the three sectors

TEMPERATURE						OCCURRENCE OF DROUGHT/WATER STRESS/WATER DEFICIT/HEAT STRESS					
Olive-Olive oil		Grape-Wine		Durum wheat-Pasta		Olive-Olive oil		Grape-Wine		Durum wheat-Pasta	
Climate Changes	*Decisions*	**Climate Changes**	*Decisions*	**Climate Changes**	*Decisions*	**Climate Changes**	***Decisions***	**Climate Changes**	***Decisions***	**Climate Changes**	*Decisions*
Increase in summer temperature	*Management of crop genetic factors*	Increase in temperature	*Use of warm climate clones*	Increase in temperature+ Soil moisture deficit	*Use of drought resistant varieties*	Prolonged and/or repeated water stress	*Water stress reducing measures*	Occurrence of water stress	*Shallow tillage*	-	-
Uneven increase in temperature across regions			*Introduction of new varieties*	-	-	-	-		*Deficit irrigation techniques*	-	-
-	-		*Late-ripening clones*	-	-	-	-	Prolonged drought + water stress	*Irrigation*		
-	-		*Grafting over more adaptable grape varieties*	-	-	-	-		*Anti-transpirant treatments*	-	-
-	-		*Rootstocks with longer cycle*	-	-	-	-		-	-	-
-	-		*Use of drought resistant rootstocks*	-	-	-	-	Occurrence of water stress	*Grafting over more adaptable*	Occurrence of drought	*Use of drought*

Increase in temperature above maximum supported by olive trees	*Irrigation*	-	-	Increase in temperature	*Irrigation*	-	-	-	*grape varieties*	Occurrence of water deficit at flowering time	*resistant cultivars*
Uneven increase in temperature across regions		-	-	Uneven increase in temperature + variable rainfall pattern	*Supplemental irrigation*	-	-	-	-		-
Prolonged increases of temperature above the maximum supported by olive trees	*Adjusted shape of olive tree*	Increase in temperature	*Adapting training system*	-	-	-	-	-	-	-	-
			Early leaf removal	-	-	-	-	-	-	-	-
-	-		*Late leaf removal*	-	-	-	-	-	-	-	-
Decrease in temperature below the minimum requirements of olive trees	*Settling olive orchards on hill slopes*		*Settling the grapevine plantation at thermally suitable altitude on hillsides*	-	-	-	-	-	-	-	-

9.2. From the scoping workshops and focus group discussions

The findings from the scoping workshops and focus group discussions indicated temperature, rainfall, air and soil humidity, and windiness as common climatic drivers of the decisions made across the olive, grape and durum wheat sectors, as illustrated in Table 9-1. In the table, the decisions are presented per groups of similar decisions.

More specifically, the groups of decisions mostly affected by ***temperature*** were related, in the order of importance, to ***the plantation design and settlement, pruning and training systems, yield estimation and harvest planning, and soil labouring activities.***

The groups of decisions mostly affected by ***rainfall and air humidity*** were related, in the order of importance, to ***phytosanitary treatments, fertilization, yield estimation and harvest planning, and soil labouring activities.***

The ***wind speed and direction*** mostly drove the decisions related to ***pruning (olive trees), training system (vineyards), and soil labouring before sowing (durum wheat).***

Table 9-2 Common climate change impacts and critical decisions identified through scoping workshops and focus group discussions across the three sectors

TEMPERATURE						RAINFALL/AIR/SOIL HUMIDITY						WINDINESS					
Olive-Olive oil		**Grape-Wine**		**Durum wheat-Pasta**		**Olive-Olive oil**		**Grape-Wine**		**Durum wheat-Pasta**		**Olive-Olive oil**		**Grape-Wine**		**Durum wheat-Pasta**	
Climate variable	***Decisions***	**Climate variable**	***Decisions***	**Climate variable**	***Decisions***	**Climate variable**	***Decisions***	**Climate variable**	***Decisions***	**Climate variable**	***Decisions***	**Climate variable**	***Decisions***	**Climate variable**	***Decisions***	**Climate variable**	***Decisions***
Temperature	*Design of plantation*	Temperature	*Vineyard installation*	-	-	Rainfall	*Phytosanitary treatments*	Occurrence of 25 mm rainfall	*Repeated phytosanitary teatments*	Rainfall	*Phytosanitary treatments*	Wind speed and direction	*Pruning*	Wind direction	*Choice of training system*	Wind speed	*Soil labouring before sowing*
	Pruning		*Use of machinery and labour for specific interventions on the training system during vegetative cycle*	-	-		*Fertilization*	-	-		*Fertilization*	-	-	-	-	-	-
	Olive yield estimation		*assessing the desired degree of grape ripeness*	-	-		*Olive yield estimation*	Occurrence of rainfall	*Assessing the desired degree of grape ripeness*	-	-	-	-	-	-	-	-
	Harvest		-	-	-		*Harvest*	-	-	-	-	-	-	-	-	-	-
	Soil labouring		-	Near soil surface temperature	*Soil labouring before sowing*		*Soil labouring*	-	-	Soil humidity	*Soil labouring before sowing*	-	-	-	-	-	-
-	-	-	-	-	-	Air humidity	*Phytosanitary treatments*	Increase in air humidity	*Phytosanitary treatments*	-	-	-	-	-	-	-	-
-	-	-	-	-	-		*Fertilization*	-	-	-	-	-	-	-	-	-	-

For better comparison, all the decisions can be visualised on a yearly basis, for the three sectors, in Table 9-3. More specifically, for the interval between January and March, there are some common decisions across olive and grapevine crops (pruning and plantation installation and design), as well as for grapevine and durum wheat crops (genetic management), and only one for all the crops (Phytosanitary treatments).

For the interval between April and May, there are common decisions only for olive and durum wheat crops (fertilization and phytosanitary treatments).

Table 9-3 Yearly calendar of decisions identified through scoping workshops and focus group discussions across the three sectors

<table>
<tr><th>Sector</th><th>Climatic driver(s)</th><th>Jan.</th><th>Feb.</th><th>Mar.</th><th>Apr.</th><th>May</th><th>June</th><th>July</th><th>Aug.</th><th>Sept.</th><th>Oct.</th><th>Nov.</th><th>Dec.</th></tr>
<tr><td rowspan="11">Olive-Olive oil</td><td>Temperature, precipitation, wind and air humidity</td><td colspan="12">Phytosanitary treatments</td></tr>
<tr><td>Temperature, precipitation and air humidity</td><td></td><td></td><td colspan="8">Fertilization</td><td></td><td></td></tr>
<tr><td>Temperature and precipitation</td><td colspan="2">Planning of fertilization</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Temperature, precipitation and air humidity</td><td></td><td></td><td></td><td colspan="7">Irrigation</td><td></td><td></td></tr>
<tr><td>Temperature, precipitation and wind</td><td colspan="3">Harvest</td><td></td><td></td><td></td><td></td><td></td><td></td><td colspan="3">Harvest</td></tr>
<tr><td>Temperature and precipitation</td><td colspan="12">Soil labouring</td></tr>
<tr><td>Precipitation</td><td colspan="2">Vegetation cover</td><td></td><td></td><td></td><td></td><td></td><td></td><td colspan="2">Vegetation cover</td><td></td><td></td></tr>
<tr><td>Temperature, precipitation, wind, and air humidity</td><td colspan="3">Pruning</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Temperature and precipitation</td><td colspan="2">Olive production estimation</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td colspan="3">Olive production estimation</td></tr>
<tr><td>Temperature, precipitation, and evapotranspiration</td><td colspan="4">Plantation design</td><td></td><td></td><td></td><td></td><td colspan="2">Plantation design</td><td></td><td></td></tr>
<tr><td>Temperature and precipitation</td><td colspan="3">Purchase and sale of fertiliser</td><td></td><td></td><td></td><td></td><td colspan="5">Purchase and sale of fertiliser</td></tr>
<tr><td rowspan="7">Grape-Wine</td><td rowspan="2">Temperature, rainfall, sun exposure</td><td colspan="3">Vineyard installation</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td colspan="2">Vineyard installation</td></tr>
<tr><td colspan="3">Choice of grapevine varieties</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Solar radiation, wind, Temperature, and water capacity of the soil</td><td></td><td></td><td colspan="5">Training system adjustment</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Temperature and rainfall</td><td colspan="2">Winter pruning</td><td colspan="4">Green pruning</td><td></td><td></td><td></td><td></td><td></td><td>Winter pruning</td></tr>
<tr><td>Rainfall, air humidity, temperature</td><td colspan="12">Phytosanitary treatments</td></tr>
<tr><td rowspan="2">Temperature and precipitation (indirectly)</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td>Green harvest</td><td>Setting harvest date</td><td></td><td></td><td></td></tr>
<tr><td colspan="12">Stock management</td></tr>
</table>

Durum wheat-Pasta	Temperature and precipitation										**Preparation of the field**		
	Temperature, precipitation, occurrence of heatwaves, solar radiation and wind speed										**Choice of variety**		
	Temperature, precipitation, occurrence of heatwaves, solar radiation and wind speed										**Sowing**		
	Temperature, precipitation, and occurrence of heatwaves	**Fertilization**									**Fertilization**		
	Temperature, precipitation, and occurrence of heatwaves	**Phytosanitary treatments**											
	Temperature, precipitation, occurrence of heatwaves, solar radiation and wind speed						**Harvest**						
	Temperature, precipitation, and occurrence of heatwaves	**Breeding and genetic improvement**									Breeding and genetic improvement		

For the interval between October and December, there are very few common decisions for the olive and grapevine crops (harvest - only in October, and phytosanitary treatments).

10. Common information needs to all the three sectors

In table 10-1, there are illustrated the information needs across the olive-olive oil, grape-wine and durum wheat –pasta sectors. However, they are not discussed here, as they were already discussed in the relevant sections.

Generally, the decadal information (mainly temperature and rainfall) was perceived as useful for long-term decisions such as the ones relating to settling of new plantations, choice of varieties, equipment purchase, and monitoring of pests, diseases and invasive species of weeds. The seasonal forecasts were mostly identified useful for the short-term decisions relating to all field activities and setting of harvest time and planning.

Table 10-1. Common information needs across the olive-olive oil, grape-wine and durum wheat-pasta sectors

Olive-Olive oil sector		Grape-Wine sector		Durum wheat-Pasta sector	
Decision	**Type of climate information**	**Decision**	**Type of climate information**	**Decision**	**Type of climate information**
Short term decisions (field activities)	7 days forecast	Maturation control planning Setting harvest dates	Seasonal forecast	Pests/disease management	Monthly forecast
Short term decisions (field activities)	3 days forecast	Stock management (products and consumables for viticulture and winemaking)	Seasonal forecast	Weed management	Monthly forecast
Short term decisions (field activities)	14 days forecast	Choice of grapevine rootstock and clone	Seasonal forecast Decadal forecast	Selection of sowing density	Seasonal forecast
	1 month forecast	Definition of training and pruning system	Seasonal forecast Decadal forecast	Fertilisation	Seasonal forecast
Harvest planning	3 to 6 months	Pest management	Seasonal forecast	Setting the harvest time	Seasonal forecast
Settling of new olive plantations/modernization	10 to 30 years	Choice of region and site for establishment of new vineyards	Decadal forecast	Monitoring emergence of new pests/ diseases/weeds	Decadal forecast
-	-	Choice of grape varieties	Decadal forecast	Equipment purchase	Decadal forecast
-	-	-	-	Choice of varieties	Decadal forecast

It should be noted that across the three sectors, there was a generally high variability of requested information, depending on the socio-economic factors accompanying the climatic changes, on the specific requirements of the three crops, and on the perceived usefulness of the olive/grape/durum wheat stakeholders

11. Conclusions

This report integrates findings from a systematic literature review, scoping workshops and focus group discussions on critical decisions affected by climate change impacts, as well as climate information needs for olive, grape and durum wheat sectors. These integrated findings represent co-produced knowledge, as a starting point in the process of co-developing tailored climate services for end users operating in the three sectors and participating in MED-GOLD project.The main integrated findings are summarized below.

The decisions across the olive, grape and durum wheat sectors, as indicated by the findings from the literature review, were mostly affected by the increase in temperature and occurrence of drought and water deficit and were related to management of crop genetic potential and water stress reducing measures (Table 9-1).

Differently, the findings from the scoping workshops and focus group discussions indicated decisions mostly affected by temperature, rainfall, air and soil humidity, and windiness, and were related to site choice and plantation design, pruning and training system, soil labouring, phytosanitary treatments, fertilization, yield estimation, and harvest timing and planning (Table 9-2).

Additionally, there were identified rather positive climate change impacts, albeit not for all the three sectors, and sometimes with tradeoffs, namely: a) a northward expansion of European grape cultivating areas, and olive growing areas – through shifting from other crops; b) a higher natural mortality of olive and grape pests under warmer and drier conditions but in parallel with the emergence of warm climate grapes' pests and diseases in northern European grape cultivating areas; c) a higher tolerance of red grape varieties to warmer and drier conditions at the same time with the lower resistance of the white grape cultivars; d) the opportunity for high quality wine production under warmer and drier conditions; e) an enhanced grapevine vigour under elevated CO2 conditions; f) an increase in grape yields but only in the areas where an increase in temperature is coupled with an increase in summer rainfall; g) an increase in durum wheat cultivation areas but only when there is an increase in autumn rainfall; and i) an increase in durum wheat yield under elevated CO2 conditions but only if there is no decrease in rainfall. Each of these positive impacts of climate change can represent opportunities to be identified and exploited by the olives, grapes and durum wheat producers, according to their specific needs. However, in this report, there were not identified any decisions associated with positive climate change impacts.

In terms of socio-economic decisions, they were both affected by climatic and economic drivers. The most common identified climatic drivers were the temperature, rainfall, and occurrence of drought and heat stress, which impacted on decisions relating to input purchase, use of modernization of machinery, labour management, stock management, harvest planning, crop insurance and supply chain contracting, at micro level. At macro level, the climatic drivers impacted on policy making to support national economic growth and development of skills to quantify climate risks. As economic drivers, there were identified the consumer preferences and the availability of manpower at regional level, and the market price at macro level, and they acted in combination with the climatic drivers.

The most common identified climate information needs across the three sectors, relate to seasonal forecasts with different leading times, which have been found to be useful for short-term decisions (field activities, stock management) and to decadal forecasts – useful for medium- to long-term decisions (choice of sites and plantation design, choice of varieties, equipment purchase, monitoring of emergence of new pests, diseases, and invasive species of weeds.

One limitation of the vulnerability analysis in this report can be that the findings relate to a narrow range of stakeholders along the olive, grape and durum wheat chains, namely producers and, to lesser extent, processors, as potential end users of climate services to be developed during MED-GOLD project. There are no findings relating to other stakeholders within (input manufacturers) or outside (advisory services, agricultural insurance companies, agricultural investors and banks) these three chains. However, these findings will be used by stakeholders outside these three chains, namely researchers from olive-olive oil, grape-wine and durum wheat-pasta research areas and climate service suppliers, to develop tailored climate services for stakeholders within the three chains, services which will potentially inform the relevant policy making later on.

Annex A. Protocol for the systematic review

This protocol includes methodological stages for a systematic literature review, namely: identification of this review' s objectives (A); search eligibility criteria (B); search terms (C); search results screening (D); data abstraction (E), risk bias assessment (F); data analysis, synthesis and presentation (G).

A. NEED FOR EVIDENCE AND OBJECTIVES OF THE SYSTEMATIC REVIEW

Needs for evidence were identified as remaining issues to be further investigated in relation to most common climate change impacts, and associated decisions and socio-economic implications, as well as climate information needs supporting the decision-making process, across most climate-sensitive European agricultural areas, with a focus on three highly sensitive crops, namely grapevine, olive trees, and durum wheat.

Objectives

The objectives of this review were:

7. To identify critical climate change impacts, and associated decisions, on olives, grapes and durum wheat production in the most climate-sensitive European producing areas;
8. To identify associated socio-economic implications of climate change impacts on olive, grape and durum wheat production in these areas;
9. To identify climate information needs of the olives, grapes and durum wheat producers operating in these areas.

B. SEARCH ELIGIBILITY CRITERIA

The selection of search eligibility criteria was driven by the focus on producing knowledge on the vulnerability of decision making to the climate change impacts on olives, grapevine, and durum wheat production, as a contribution to the first stage towards developing the pilot climate services within MED-GOLD project.

For this purpose, this protocol was based on the adapted approach taken by Ford *et al.* (2011). Therefore, this review was performed on specialized databases from the field of social sciences (Table 1), to help targeting relevant recent (2000-2018) English peer-reviewed literature (Table 1). Additional grey literature (books, European project reports) was reviewed on non-specialized databases (Table 1).

Table 1. Search eligibility criteria

SEARCH ELIGIBILITY CRITERIA	
INCLUSION CRITERIA	**EXCLUSION CRITERIA**
SPECIALIZED DATABASES: **Web of Science Core Collection**: Social Sciences Citation Index (SSCI)	**NON-SPECIALIZED DATABASES:** **Web of Science Core Collections:** Science Citation Index Expanded (SCI-EXPANDED) Arts & Humanities Citation Index (A&HCI) Conference Proceedings Citation Index- Science (CPCI-S) Conference Proceedings Citation Index- Social Science & Humanities (CPCI-SSH) Emerging Sources Citation Index (ESCI)
SCOPUS : E-databases -- Social Sciences -- Sociology/Social Policy	**SCOPUS:** E-databases -- Medicine, Dentistry, Psychology & Healthcare E-databases -- Arts E-databases -- Business School E-databases -- Performance, Visual Arts & Communications E-databases -- Social Sciences -- Education E-databases -- Social Sciences -- Law E-databases -- Social Sciences – Politics
PROQUEST : Applied Social Sciences Index & Abstracts (ASSIA)	**PROQUEST :** ABI/INFORM Collection British Periodicals Linguistics and Language Behavior Abstracts (LLBA) Periodicals Archive Online ProQuest Dissertations & Theses: UK & Ireland ProQuest Dissertations & Theses A&I ProQuest Historical Newspapers: The Guardian and The Observer ProQuest Historical Newspapers: New York Amsterdam News ProQuest Historical Newspapers: The New York Times Sociological Abstracts The Vogue Archive Worldwide Political Science Abstracts
SCIENCE DIRECT: Social Sciences and Humanities/Social Sciences	**SCIENCE DIRECT:** Social Sciences and Humanities/Arts and Humanities Social Sciences and Humanities/Business, Management, and Accounting Social Sciences and Humanities/Decision Sciences Social Sciences and Humanities/Economics, Econometrics, and Finance Health Sciences Physical Sciences and Engineering
SAGE JOURNALS: Social Sciences & Humanities	**SAGE JOURNALS:** Health Sciences Materials Sciences & Engineering Life & Biomedical Sciences
ADDITIONAL SOURCES OF PUBLICATIONS: **OPEN SCIENCE FRAMEWORK** **GOOGLE**	

<table>
<tr><td>CORDIS DATABASE</td><td>ADDITIONAL SOURCES OF PUBLICATIONS :
-</td></tr>
<tr><td>Language: English</td><td>Language: All the other languages</td></tr>
<tr><td>Time frame: 2000-2018</td><td>Time frame: 1900-1999</td></tr>
<tr><td>Search field(s): topic/subject/keywords (depending on the options of each database)</td><td>Search field(s): author, title, source</td></tr>
<tr><td>Type of publications:
- Peer-reviewed publications (journal articles)
- Grey literature/not peer-reviewed publications:
○ Books
○ Book sections/chapters
○ Relevant European project reports</td><td>Type of publications*:
Abstract of published item
Art Exhibit review
Bibliography
Bibliographical item
Book review
Chronology
Correction
Correction, Addition
Dance performance review
Data paper
Database review
Discussion
Early access
Editorial Material
Excerpt
Fiction, Creative Prose
Hardware Review
Item about an individual
Letter
Meeting abstract
Meeting summary
Music performance review
Music score
Music score review
News Item
Note
Poetry
Record review
Reprint
Retracted publication
Retraction
Review
Script
Software review
TV review, radio review video
Theatre review</td></tr>
</table>

C. SEARCH TERMS AND COMBINATIONS OF TERMS

The following combinations of search terms were used, to search for literature related to all the derivations of the truncated search terms. The derivations of the truncated words were checked with CAB Thesaurus (Anonymous, 2018*a*).

climat*

AND one of the followings: **grape** / **vine** / **durum wheat** / **oliv***

AND

Europ*

By using "AND" Boolean operator, we narrowed down the search, as this operator requires to be included at least one search term from the lists given on each side of the operator (Anonymous, 2018*b*).

The initial search retrieved a number of 1747 peer-reviewed and grey documents .

D. SEARCH RESULTS SCREENING

After the search was finalised, the titles, abstracts and key words of the search results were screened according to the eligibility criteria (Bernes *et al.,* 2018).

There were retained 68 results, including peer-reviewed and grey literature, for data abstraction phase.

E. DATA ABSTRACTION

After screening and study identification, key data (Table 2) were abstracted into data abstraction forms. These forms were centralized in one single centralized Excel form including the data for all the abstracted studies.

The centralized data abstraction form documented general and specific information (Table 2) to be further used in data analyses (Söderström *et al*., 2014).

Table 2. Types of data to be abstracted from individual studies for systematic review of climate change impacts, critical decisions, and information needs across grape-wine, olive-olive oil, and durum wheat-pasta sectors

Types of data abstracted from individual studies
General information: **Name** of data abstractor: **Version number**: **Date** of data abstraction: Other (please specify):
Study/publication characteristics: **Title/year/author(s)** **Type**: review or research paper **Addressed research gap(s)** **Aim or objectives** of the study/publication Other (please specify) **Study design**: Region(s) and country/countries from which study participants were recruited Recruitment and sampling procedures Sample size Start and end dates Methods used to prevent and address missing data and uncertainty Level of addressing the identified research gap(s) Other (please specify)
Identified independent variable(s): Grape-wine/Olive-olive oil/Durum wheat-pasta sector/Common to all sectors
Identified dependent variable(s): Climate change impacts/critical decisions of relevant

	stakeholders operating within grape-wine/olive-olive oil/durum wheat-pasta sectors
Confounding variables or effect modifiers: politico-historic-economic context and policy context (in case of significant differences among EU and non-EU countries)	
Rejected (yes/no)	
Reason for rejection	

(Adapted from Li *et al.,* 2015)

In terms of number of abstractors, it has been previously accepted that "Sometimes, especially for larger reviews, a single reviewer may perform the primary data abstraction, and the secondary reviewer may independently abstract key data elements (particularly those that go into analysis) and confirm abstraction of random data elements across multiple studies" (Singh *et al.,* 2017).

F. RISK BIAS ASSESSMENT

We performed critical assessment of study quality, through a combination of identified factors that may bias review output.

For this systematic review, we took into consideration the following types of biases:

- Biases (systematic errors) in the search strategy, which may affect the search outcomes operator (Anonymous, 2018*b*);
- Possible publication bias, where 'positive' (i.e. confirmative, statistically significant) results are more likely to be published in academic journals rather than in grey literature operator (Anonymous, 2018*b*);
- Confounding during data abstraction process **(**Viswanathan *et al.,* 2012; Li *et al*., 2015)

We attempted to minimize biases in the search strategy and publication bias by:

1) looking for evidence outside traditional academic electronic bibliographic sources, such as Open Science Framework, Goggle Scholar, and CORDIS as well as in non-peer-reviewed sources (books and book chapters, relevant European project reports; Table 1).
2) using multiple specialized databases to reduce the possibility of bias in the retrieved results (Söderström *et al*., 2014) (Table 1).

We attempted to minimize confounding by identification of potential factors which might be potential confounding variables or effect modifiers (i.e., correlated with other factors) (Singh, 2017; Bernes *et al.,* 2018)

The following potential confounding variables or effect modifiers were considered and recorded in the review (Table 2):

- politico-historic-economic context (in case of significant differences among EU and non-EU countries)
- policy context (in case of significant differences among EU and non-EU countries).

G. DATA SYNTHESIS AND ANALYSIS

The identified climate change impacts/critical decisions for the three crops (olive tree, grapevine, and durum wheat) and associated products (olive oil, wine, and pasta) were encoded as nodes in NVIVO and grouped into specific types and sub-types, by running several queries, as follows:

- OLIVE/OLIVE OIL SECTOR
  - Climate impacts and decisions related to:
    - Cultivation areas

    - Olive tree development and phenology
    - Olive fruit and oil quality
    - Pests and diseases
    - Yield
- GRAPE/WINE SECTOR
  - Climate impacts and decisions related to:
    - Cultivation areas
    - Grape varieties and rootstock
    - Grapevine development and phenology
    - Grape and wine quality
    - Pests and diseases
    - Yield
- DURUM WHEAT SECTOR:
  - Climate impacts and decisions related to:
    - Cultivation areas
    - Varieties
    - Plant development
    - Yield
- COMMON VULNERABILITIES TO ALL THE THREE SECTORS

It worth noting that all the identified positive climate change impacts, and related opportunities, were distinctly encoded from the negative ones, to be presented separately.

Cluster analysis, with Pearson coefficient, of the nodes was performed in NVIVO to:

- Identify common climate change impacts and related decisions across the three crops;
- Verify the relationships between climate change impacts and related decisions for the three crops.

The values of Pearson coefficient were calculated in NVIVO to measure the linear correlation for each pair of climate change and related decision.

The statistical significance was verified by deriving P-values for the investigated correlations and the calculated Pearson coefficients by using the P Value from Pearson Calculator for social science statistics (Anonymous, 2019).

Annex B. List of references

MED-GOLD project reports

RD1. MED-GOLD project research proposal, 55 p.

RD2. Deliverable D 4.1. “Report on the identified specific needs and opportunities”, 14 p.

RD3. Deliverable D 2.1. “Report on the Knowledge capitalization of the olive oil sector”, 29 p.

RD4. Deliverable D 3.1. “Report on the two case studies at seasonal- and long-term timescales for the wine sector”, 27 p.

Literature review

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Anonymous (2019) *Quick P Value from Pearson (R) Score Calculator*. Available at: https://www.socscistatistics.com/pvalues/pea [Accessed 11th January 2019]

Agencia Estatal (2015). “Final Report Summary - MOLCHARAVITIS (Study of the molecular mechanisms involved in the beneficial effect of high CO_2 levels to preserve table grape quality during the storage at low temperature)”, MOLCHARAVITIS project.

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