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Review

A Review on the Observed Climate Change in Europe and Its Impacts on Viticulture

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Abstract: The European climate is changing displaying profound impacts on agriculture, thus strongly reaching the scientific community's attention. In this review, the compilation of selected scientific research on the agroclimatic conditions' changes and their impact on the productivity parameters (phenology timing, product quality and quantity) of grapevines and on the spatiotemporal characteristics of the viticultural areas are attempted for the first time. For this purpose, a thorough investigation through multiple search queries was conducted for the period (2005–2021). Overall, increasing (decreasing) trends in critical temperature (precipitation) parameters are the reality of the recent past with visible impacts on viticulture. The observed climate warming already enforces emerging phenomena related to the modification of the developmental rate (earlier phenological events, shortening of phenological intervals, lengthening of the growing season, earlier harvest), the alteration of product quality, the heterogeneous effects on grapevine yield and the emergence of new cool-climate viticulture areas highlighting the cultivation's rebirth in the northern and central parts of the continent. The vulnerability of the wine-growing ecosystem urges the integration of innovative and sustainable solutions for confronting the impacts of climate change and safeguarding the production (quantity and quality) capacity of viticultural systems in Europe under a continuously changing environment.

Keywords: temperature increase; climate warming; warming trends; European viticulture; grapevine; wine grape phenology; grape quality; berry quality; grapevine production; viticultural area

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1. Introduction

In the 21st century, mankind faces climate change (CC) (Appendix A) as one of the greatest environmental endangerments, given that it poses a significant political, economic and social challenge [1–4]. The consistent temperature increase dominates as the quantifiable component of CC, which has triggered major changes already apparent in the global hydrological and energy cycles [3,5]. These changes, in turn, have increased the frequency, intensity and duration of extreme weather events (e.g., heat waves, drought occurrences or extreme precipitation) [6–9].

The weather conditions which prevail throughout the life cycle of crops consist of fundamental abiotic factors for their growth [2,10], and therefore determine both the quantity and quality of agricultural production and, consequently, its economic sustainability [11,12]. CC risk, therefore, particularly defines the success of agricultural systems among the different sectors of human activity (e.g., energy consumption, forestry and tourism) [13–16].

The European continent is highly responsive to the temperature increase induced by CC [17]. Furthermore, CC projections over several European regions reveal steady warming throughout the 21st century [18]. By considering that recent past trends in the growing season mean (or average) temperatures (Appendix A) which have already shown increases (by 1.7 °C from 1950 to 2004) [19], it becomes apparent that special attention must be drawn towards the prominent perennial crops which are typically grown in Europe.

Grapevine (*Vitis vinifera* L.) is included in the aforementioned category constituting a representative plant species with a prolonged cultivation history in Europe since the second millennium B.C. [20]. Today, grapevine is primarily acknowledged as one of the most significant crops cultivated across Europe, which demonstrates a fundamental socioeconomic role [18] and is also extensively used in CC studies given that it is distinguished as a biological model of long-lived perennials [21,22].

Globally, Europe ranks first in terms of wine production and viticultural area and hosts some of the most significant and distinguished wine-making regions and wines [23]. These are especially predominant in Italy, France and Spain, which consist of the world's top wine-producing countries [23], where warming trends comprise an inevitable reality; e.g., annual mean temperature increase by 2.1 °C in Bordeaux (France) and growing season mean temperature rise of 2.3 °C in Veneto (Italy) in approximately five decades [17,24].

The climate conditions constitute major forcing factors on grapevine development and growth since they substantially control canopy microclimate, vine physiology and development, and product quality and quantity and therefore play a dynamic role in a specific terroir (Appendix A). Although many individual atmospheric parameters such as solar radiation, wind and air humidity may influence the growth and productivity of grapevines, specific thermal and hydrological conditions appear as the most important [19,25–29]. In fact, these are the two factors most frequently addressed in the scientific community's research domain on CC and its impacts on viticulture [18]. In addition, it should be emphasized that climate change may importantly impact the viability of vineyards, given that grapevine is a perennial plant with an expected economically productive lifespan of approximately 30–40 years [30], during which projections on climate reveal significant changes [18].

As a perennial crop, grapevine requires both adequately cold and sufficiently warm periods in order to implement its biological processes (e.g., low temperature for hardening and fruitfulness and high temperatures for berry ripening). Thus, the temperature may be considered one of the main drivers of the growing cycle's evolution and of the final maturity and berry composition [31–35].

The geographical areas in which grapevine is traditionally cultivated are characterised by a temperature range of 12–22 °C during the growing season, in which daily temperature values from 20 to 35 °C result in the vine's optimal vegetative response [12,36,37]. The initiation of the growing/vegetative cycle, but also the storage of carbohydrate reserves in perennial organs necessary for the subsequent year growth, require bud dormancy breaking through winter chilling with a base temperature of 10 °C [38–41]. Freezing injuries may be caused under extremely low negative temperatures in winter and spring, significantly impairing grapevine development [42,43]. However, the minimum values of temperature that vine may tolerate range between −5 and −20 °C, while the variation in resistance is attributed to the variety, location and management of the vineyard but also to the timing and duration of the adverse event [44,45].

On the contrary, the vine may be benefitted under the regime of high temperatures during the ripening period [35,46]. However, excessive temperatures may trigger plant stress and cause photosynthesis reduction [35,47,48]. In addition, under conditions of extreme temperatures, metabolic processes and sugar accumulation may be terminated [49–51]. The plants' higher evaporative demand under the prevailing elevated temperatures may result in higher sugar concentrations in the berries but also their reduced size and weight [49]. Impairment of vegetation activity occurs above 35 °C, while in some extreme cases, vineyards may be severely and irreversibly damaged [52,53]. When exposed for an extended period to temperature extremes (values higher than 35–40 °C), the plant's photosynthetic system can be negatively affected [52], and sunburns appear owing to serious severe skin damage, which may increase the incidence of Botrytis latent infections in the grapes [54].

Grape composition and flavour development may also be impacted, given that fruit ripening is accelerated under elevated temperatures [55–58] and is most commonly described as the increase in the sugar content versus the faster breakdown of acids in the grape, which leads to higher alcohol and lower acidity in the resulting wine [25,59]. These impacts may appear by modification of secondary metabolites such as flavonoids (e.g., anthocyanins), amino acids and carotenoids, also effecting aroma and colouration [32,35,60–63]. It has been recently demonstrated that negative correlations between temperature and berry weight, titratable acidity, anthocyanins and positive correlations with pH and the potential alcohol content may exist at technological maturity [50,64–68].

The outset of bud break, flowering and veraison (see "Phenophases or phenological phases-stages-events of the grapevine" in Appendix A) is determined by temperature, which affects the date of harvest, yield performance and composition [69]. Therefore, the thermal conditions regulate the duration of the phenological phases, stages or events (Appendix A) and eventually the growing season's length [70].

The shortening of the ripening period places harvest under conditions of elevated temperatures, which may negatively impact production [17,71,72]. The prevailing higher temperatures lead to higher rates of evapotranspiration [25,44,73,74] which may drive the vine's water status. Hence, a warmer climate may also be characterised as a dryer climate, even when there is no rainfall reduction [75]. In this case, the rising temperatures may trigger higher water requirements, and the vines may be subjected to higher drought stress, especially in the case of limited or absent irrigation capacities (e.g., rainfed vineyards), thus disrupting the physiological processes of plants such as grapevine photosynthesis and leaf transpiration [76]. This, in turn, constitutes a widespread constraint of production by accounting that vineyards are mainly rainfed in Europe [77,78]. Temperature broadly confines the geographical distribution of grapevines [79], including a strong association with the variability in grapevine yield [80], wine production [81,82] and quality [49,83].

Precipitation and its temporal distribution also comprises a crucial atmospheric element influencing grape development as it largely governs soil moisture and the water potential of grapevine, especially in non-irrigated vineyards [84–88]. High soil moisture is essential during bud break, shoot and inflorescence development, succeeded by dry and invariable atmospheric conditions from flowering to berry ripening [17,70,89]. Surplus soil moisture prevailing during the growing season may promote extensively shaded canopies owing to excessive vigour. This may lead to detrimental effects on the performance of the vine such as bud break reduction, maturity delay, berry weight increase and the degradation of fruit and wine quality [90]. Abundant precipitation engenders the development of drowned vines and excessive humidity overstimulates the growth of vegetation, forming denser canopies and a higher likelihood for the promotion of plant epidemiology (e.g., leaf and inflorescence diseases), with negative impacts on productivity [91–93]. Humid summer periods preceding the vintage can be related to more extensive grape damage or loss probability. Impacts include also lower grape production in the subsequent annual campaign owing to bud damage [94]. During ripening, excessive humidity promotes sugar dilution and therefore is disadvantageous to maturation [95], while moderate dryness enhances product quality [96].

Grapevine displays relative resistance to drought in comparison to other crops [97]. This is not the case under severe dryness [98], where a substantial risk for water deficit may be possible, especially during the initial stages of the crop's annual growth cycle [99–101]. Water deficit is one of the principal abiotic factors which limits vegetative growth and grapevine yield [102,103], given that it generates stomata closure [104], it impairs photosynthesis [105,106] and shoot growth [107] and reduces the size of the berries [108,109]. On the other hand, research indicates that increased water deficit may promote the accumulation of important constituents in the berries as it may increase malic acid [110] and flavonol concentrations [111], the grape tannin, anthocyanin and procyanidin content [112–116].

The evaluation of changes in the climate of wine regions over the past decades is mainly conducted through the recording and measurement of temperature and precipitation parameters on a daily, monthly, seasonal or annual basis. Typical examples of the regional climate parameters encountered in climate impact assessments include the mean temperature, the maximum temperature and the minimum temperature. The study of simple temperature and precipitation values is insufficient to explain the trends in CC due to the vast complexity of climate modifications. Therefore, the comprehension and interpretation of the CC trends by using selected bioclimatic indices comprise the most common procedure for evaluating the impacts of CC on viticulture. Some of the most used are the heat summation indices, e.g., HI: Huglin index [117], CI: cool night index [118], WI: Winkler index [38] or GDD: growing degree days index [44], the GST: mean growing season temperature [119] and the number of days with maximum temperatures higher than 30 °C [73]. Most indices are mainly formed on air temperature as it comprises the most influential parameter of the overall growth, productivity and berry ripening of the grapevine [12]. Furthermore, the assistance of these indices in defining viticultural regions in relation to their climatic conditions is of fundamental importance. This is due to the substantiality of the results obtained that, in general, refer to the ability of an area to produce grapes, the best adapted varieties there, as well as the timing (precocity or lateness) of the varieties' phenological stages [118]. In addition to their use as tools for the identification of changes in specific climates of major wine regions worldwide, bioclimatic indices have also allowed the forecasting of spatial shifts in viticulture areas as a result of CC [120–125]. Furthermore, research on the impact assessment of CC is based upon long ampelographic records on phenology development (Appendix A), berry composition and yield data along with references on vineyard observation collections [126–128].

The unsustainable development of viticulture in Europe seems to be a forthcoming major scientific research challenge, given the catalytic relationship between climate and vine performance in conjunction with CC, which is an ongoing spatiotemporal reality. According to the latest review on the future impacts, foreseen CC points to shifts in European grapevine production patterns [18]. However, when attempting to estimate the impact of CC in the future, it is essential to reflect on information collected from a starting point comprising results from the past to the present.

Extensive research has been conducted concerning the aforementioned context, thus motivating this first attempt for the compilation of relatively recent scientific studies conducted from 2005 to 2021 and which focus on the past to present CC (during approximately the last 30 to 60 years in most cases) and its impacts on European viticulture. This review focuses exclusively on the climate evolution and its effects on essential productivity parameters such as phenology timing, product quality and yield level, but also on the documented spatiotemporal characteristics of viticultural areas.

The compiled scientific outcomes of this work are of fundamental importance given that the identification and realisation of the phenomenon of CC and its impacts that have occurred to this day aid in the assessment of possible future effects but also in facilitating and delineating proactive measures (e.g., adaptation and mitigation strategies), both aiming for the potential assurance of the pan-European viticultural sustainability under an ongoing changing climate.

2. Materials and Methods

In this review, the assessed studies were published from the years 2005 to 2021 and link the findings on CC trends to the recent past European viticulture. The studies describe the changes in climatic parameters and how these changes have impacted phenology timing, product quality and quantity and the spatiotemporal characteristics of viticultural areas. The included scientific studies are published articles in peer-reviewed journals. The international acceptance and comprehension by most stakeholders, scientists, policymakers and producers focused the authors' interest on studies published in English. The implementation of multiple search queries within Google Scholar, Scopus and Web of Science are based on different combinations of the keywords shown in Table 1.

Table 1. Keywords utilised for the implementation of multiple search queries.

Keywords Related to:			
Climate	**Wine**	**Grape**	**Vine**
climate change	wine sector	grapevine (s)	vine grape yields
climate warming	wine grapes	grapewine	viticulture
thermal climate	wine production	grape quality	*Vitis vinifera* L.
regional climate change	wine yields	grape maturity	viticultural zoning
climate risk	wine grape production	grapevine yield	vineyard(s)
climatic factors	wine regions	grape phenology	vine varieties
	wine quality	grape ripeness	European viticulture
	wine typicity	grape harvest	
	winegrapes		
Other supplementary or auxiliary keywords: growing season temperature; seasonal temperature; agrometeorology; agroclimatology; temperature; warming; global warming; precipitation; seasonal precipitation; rainfall; drying; water deficit; agricultural risk; agriculture; agricultural crops; impacts on agriculture; impacts on viticulture; terroir; topoclimate; bioclimatic indices; thermal indices; agro-climatic indices; Huglin index; growing degree days; growing season; development stages; phenological stages; phenological phases; phenophases; phenological intervals; growth period; early/late ripening; harvest dates; composition; fruit composition; quality; sugar concentration; titratable acidity; acid concentration; alcoholic content; alcoholic degree; berry sugar concentration; berry quality; berry ripening; flavour development; crop yields; yield formation; grapevine cultivars; adaptation			

In order to visualize the papers' keywords connections to the selected bibliography, we used the bibliometric software VOSviewer (version 1.6.17; Leiden University, Leiden, The Netherlands) [129]. The input file for this analysis contains all citations used for this study, including information about the authors' names, the title, the journal's name and the digital object identifier (DOI), and the output depicts the publications' keywords relationships. The citations' visual analysis shown in Figure 1 represents the connections of the most frequent keywords of the selected publications. It is evident that climate change is the dominant keyword of the analysed papers, followed by viticulture. The size of the knots and the lines are related to the occurrence frequency. Finally, this graph indicates that the selection of the studied bibliography is appropriately balanced, taking into account its scope.

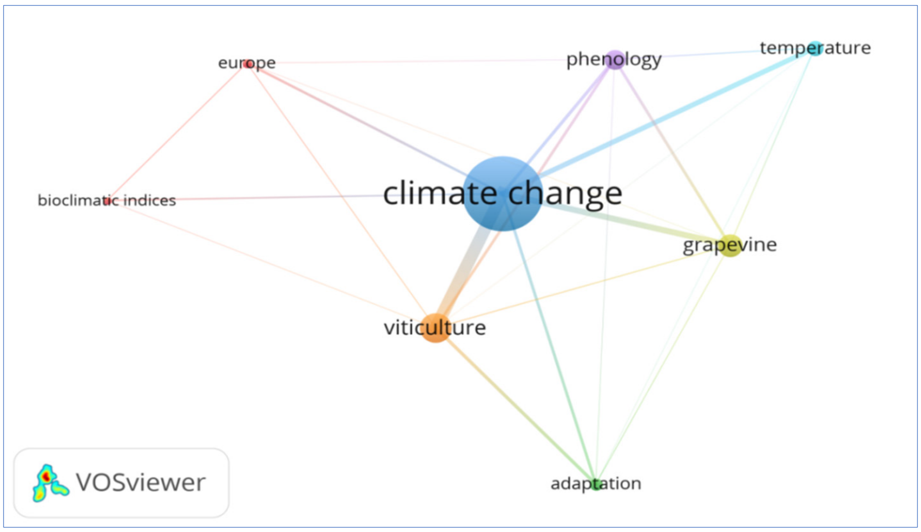

Figure 1. The citations' network via the VOSviewer software.

After completion in December 2021, the retrieved results of a total of 107 articles were further examined on the basis of their absolute coherence with the subject of this review, namely, the description of the changes in fundamental agroclimatic conditions (see "Agroclimatology" in Appendix A) and their impacts on viticultural productivity parameters (in terms of phenology timing, quality and yield) and on spatiotemporal characteristics of viticultural areas. A systematic assessment of the references in key publications was implemented for additional literature. In total, this review comprises 40 published journal articles presented in Appendix B.

The articles were sorted by country accompanied by the specific region(s) where each study was applied (Appendix B, columns 1 and 2) and followed in consecutive order by: synoptic information on the time period representing the climatological data record (Appendix B, column 3), a symbolic presentation of the changes in the agro-climate and bioclimate parameters (Appendix B, column 4), a synoptic description of the impacts of CC on viticulture (Appendix B, column 5), and finally the respective reference for each study (Appendix B, column 6). In addition, a map (Figure 2) illustrates the labelled vine regions mentioned in this review.

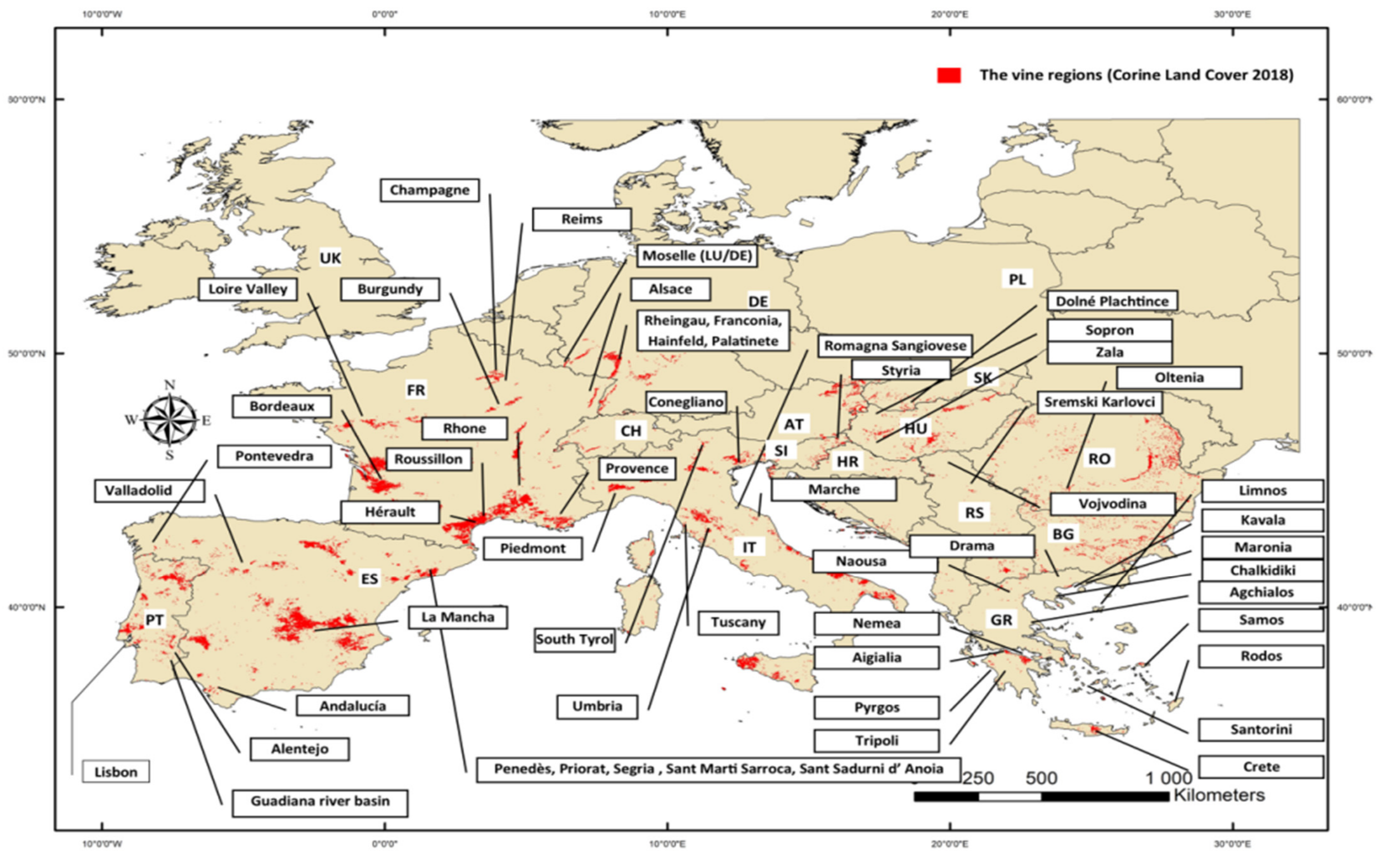

Figure 2. The vine regions reviewed. The viticultural regions not detected by the CLC (Corine Land Cover) 2018 are not displayed.

It must be underlined that the authors' attention was focused exclusively on the direct effects of CC, thus excluding its indirect effects (e.g., the outbreak of vine epidemiology owing to prevailing ideal climatic conditions).

3. Results

3.1. Observed CC and Its Impact on Phenology

A study conducted by Jones et al. (2005) [17] on nine European wine-growing areas located in France, Italy, Spain, Germany, and Slovakia confirmed a strong correlation between the growing season (April to October) temperature and the phenological development of 15 varieties. The analysis of the time series of at least 50 years, between 1952 and 1971, and 2003 and 2004, has highlighted warming trends and increases in heat accumulation indices, clearly influencing changes in the phenological cycle of the winegrapes. An average warming of 1.7 °C during the growing season and an increase in the GDD (average change of 264 units) and of the THI (average change of 285 units) was shown for most regions (e.g., Colmar, Reims, Bordeaux, Conegliano Veneto, Geisenheim, and Vallaloid). Growing season precipitation showed the least change, with only regions in Spain (Pontevedra) and France (Bordeaux) experiencing increasing trends. Warming during the last 50 years has resulted in significantly earlier phenological events (6–18 days) with shorter phenological intervals (Appendix A) between events (4–14 days) in most of the 20 examined locations–vine combinations. The phenomenon mainly affected bloom, veraison and harvest, although significant advances have also occurred according to bud-break data of Riesling and Pinot noir in Alsace and Burgundy.

These findings are corroborated by the work of Duchêne and Schneider (2005) [71] who attributed similar phenomena to the warming trends which have been recorded during a 30-year period (1972 to 2003) in the Alsace vine-growing area (eastern France). Annual mean temperature data have shown an increasing tendency (average trend of 0.06 °C per annum), resulting in almost 2 °C over the 30 years examined. Furthermore, there was also a significant increase in the HI (+14.3 degree-days per year) observed from April to September. According to the researchers, the significant increases in temperature are responsible for the advancement of phenophases (Appendix A); e.g., budburst and flowering by 4 days per decade and veraison by 1.7 days per decade. The shortening of the phenological intervals; e.g., shrinking of the period between flowering and veraison by 8 days and occurrence of the veraison date 23 days earlier, is also attributed to the temperature warming. The mean annual temperature increase has demonstrated significant special effects during the ripening phase. In 2002, compared with 1972, 33 additional days with a mean daily temperature above 10 °C were recorded, resulting in a two-week earlier harvest. It is highlighted that the time of harvest in Alsace for Riesling used to occur up to mid-October, while in recent years, harvests more frequently occur in early September (in the first week) and sometimes even late August.

Even higher advancement of harvest dates has been demonstrated for southern France by Laget et al. (2008) [130]. Climate data analysis between 1950 and 2006 in the Hérault department (Mediterranean of France) has shown increases in mean annual temperatures of 1.3 °C between 1980 and 2006 (compared to 0.2 °C for the period 1950–1980). These increases were accompanied by rises in the mean potential evapotranspiration from April to September, averaging 900 mm since 1999, and in the total solar radiation, exceptionally between 1992 and 2006, with an increase of approximately 40,000 joules per cm^2. The HI evolved during the growing season, with the result that central and eastern zones previously (1975 to 1996) classified as "warm—temperate" ($2100 < HI \leq 2400$ units) were subsequently (1997 to 2005) classified as "warm" ($2400 < HI \leq 3000$ units). These changes in the vines' agroclimatic environment have led to the advancement of the harvest dates by up to three weeks.

Significant correlations between earlier harvests and temperature warming have also been found by Neethling et al. (2012) [131] for the northwestern parts of France between 1960 and 2010. Results have shown significant increases in the growing season mean temperature (by 1.3 to 1.8 °C) throughout the Loire Valley and more substantial increases in the maximum temperatures compared to the minimum temperatures. Temperature variables, along with bioclimatic indices, have increased significantly. For example, the HI calculated for six locations demonstrated the shifting from a "cool" ($1500 < HI \leq 1800$ units) to a "temperate" ($1800 < HI \leq 2100$ units) climate, while increases in the GDD (a greatest increase of 360 units) were highly correlated with earlier harvest dates. For Cabernet Franc, the harvest date has advanced significantly by 15 and 16 days in the Chinon and Bourgueil regions, respectively. These earlier occurrences are in line with the general 2-week advancements of harvest in France.

By exploiting historical harvest and climate data over the 20th century, Cook and Wolkovich (2016) [132] investigated the climatic controls of wine grape harvest dates in France and Switzerland. A rate of early harvests occurs with warmer temperatures (e.g., average of −6 days per 1 °C), and harvests are delayed by wet conditions (e.g., +0.07 days per

1 mm) during spring and summer. Mean harvest dates were moderately early during the first 50 years (–5.2 days for 1901–1950) in contrast with the substantially earlier (–10.2 days) occurrence of average harvest dates in more recent decades (1981–2007). Historically, elevated temperatures during the summer period in Western Europe, which would have accelerated fruit ripening, required drought conditions to generate extreme heat. The researchers point out that in recent decades (1981–2007) the connection between drought and the timing of harvest has broken down, given that the enhanced anthropogenic warming generates the necessary increased temperatures for early harvests in the absence of drought. Thus, they suggest that CC has fundamentally modified the climatic factors of early wine grape harvests, indicating a significant change in the role of drought and moisture availability with probable ramifications for viticulture management and wine quality. Thus, as evidenced by long-term grape harvest date records, warm temperatures have been consistently driving advanced harvests, while the relationships with drought have perished in recent decades.

By using long term site-specific climate and phenology datasets of multiple cultivars (e.g., Müller Thurgau, Pinot Grigio, Chardonnay, Franconia, Pinot Noir), Tomasi et al. (2011) [24] examined the relationships and trends for climate and grapevine phenology in Conegliano (Veneto region, northern Italy). According to their results, the growing season mean temperatures have warmed by 2.3 °C from 1964 to 2009. Maximum temperatures have increased the most, warming 2.4 °C over the growing season, and minimum temperatures have increased by 2.0 °C over the respective period. The increase in the growing season's mean temperatures has shown significant relationships with harvest dates (e.g., a 1 °C warmer vintage resulted in an 8-day earlier harvest). Trends in phenological timing showed 13 to 19 days advancement for bloom (e.g., 4.1 days earlier per 1 °C increase in maximum temperatures during April–June) and veraison (e.g., 3.2 days earlier per 1 °C increase in maximum temperatures during June–August). The intervals also displayed trends, indicating that the duration between phenological events is getting shorter by changing the most at 18 days shorter for budbreak to bloom, at 15 days for both budbreak to veraison and budbreak to harvest and at 6 days for veraison to harvest.

Di Lena et al. (2019) [133] analysed the CC impact in some wine-growing areas of the Abruzzo region (central Italy) during the period 1974–2013. They concluded that the estimated CC, led to a significant reduction in the period between budburst and harvest of the Montepulciano vines. The beginning of harvest dates was significantly correlated with the increases in mean annual temperatures and in all of the bioclimatic indices tested (e.g., see HS, HI, NHH, GDH, GI, HTE in Appendix B). In the southern coastal and internal hills, the approximate period between budburst and harvest was 23 and 25 days shorter, respectively. This was mainly attributed to the earlier beginning of the harvest dates by 18 and 19 days in the southern coastal and inland hills, respectively, and less than 18 days in the central coastal hill. In their previous study on the effects of CC on the Montepulciano harvests, Di Lena et al. (2012) [134] compared data observed in the same region to data from Bordeaux (southwestern France). They concluded that the bioclimatic thermal indices (e.g., see AT, HI, NHH in Appendix B) cumulated during the years 1974–2009, in each area examined, displayed moderate to strong relations with earlier harvests. These relations support the inverse connection between the thermal resources' level and the date of harvest. The dates of harvest were significantly and negatively correlated with growing season mean temperatures occurring during the main period of March to September, in each viticultural site. The number of hot days with maximum temperature exceeding 30 °C and the daily thermal range displayed the highest correlation with mean harvest dates in Bordeaux. This was not the case for the beginning of the harvest in Abruzzo, where their impact was weaker. The advancement of the Montepulciano harvests ranged from 10 days in the Abruzzo southern maritime area and in Bordeaux to 14–15 days in the inland zone and central maritime area of the Abruzzo. The analysis revealed that the shift in climate which took place in the 1980s advanced harvesting in France and that similar advancements are also a reality for the Abruzzo region.

By utilising the grape harvest dates (1820–2012) of premium white wine (Trebbiano d'Abruzzo) in the Abruzzo region (central Italy), Di Carlo et al. (2019) [135] found that since 1960, the annual harvest dates of the white wine have been getting earlier. This was attributed to temperature increases (−5.92 days per 1 °C) and more intense precipitation events occurring (−1.51 days per (mm/number of rainy days)) during the growing season. The innovative findings of their work indicate the fundamental impact of the precipitation intensity on grape wine phenology that exacerbates the respective effect of the increasing temperature (while the total amount of rain induces a delay of the grape harvest date, the precipitation intensity has the opposite effect). Their analyses substantiate that global warming is impacting on the premium wines in central Italy, inducing early grape harvest dates and at similar rates to those observed in other European countries (e.g., France, Switzerland and Spain).

Long-term climate observations (1995–2015) conducted by Biasi et al. (2019) [136] in the Umbria region (central Italy) underlined important weather modifications over time. In particular, the annual mean temperature increased over the examined two-decade period, and an increasingly linear trend was exhibited for the growing season temperature (increase by 1.4 °C between 2000 and 2015). Bioclimatic indices (e.g., see WI, HI and CI, in Appendix B) calculated for the studied grapevine growing area displayed increasing values over time. The response in the ripening date was specified highly by genotype and differed among native and international grapevine varieties and between red and white grape varieties. The red grape autochthonous varieties (e.g., Aleatico) displayed no significant trend in the date of ripening, in contrast with the international red varieties (e.g., Sangiovese and Cabernet sauvignon) among which some exhibited a delay in fruit maturity as demonstrated by the higher number of days required for technological maturity but also the anticipated harvest dates (e.g., Merlot and Cabernet Franc).

A regular and constant temperature increase reaching 4 °C during the budding season has been measured in the last 25 years by Ferretti et al. (2021) [72]. This climatic evolution in the province of South Tyrol (northern Italy), has induced an earlier vegetative cycle and ripening and has caused the harvest to occur approximately 3 to 5 weeks earlier. It is noteworthy that measurements on the harvest day of Sauvignon Blanc "Voglar" in the most southern part of South Tyrol reveal that in the early 1990s, the harvest was normally carried out in early October, while in recent years, harvesting has taken place almost over a month earlier, at the end of August.

For 1952 to 2006, in the Alt Penedès, Priorat, and Segrià regions of northeastern Spain, Ramos et al. (2008) [73] have reported changes in many temperature parameters characterised by an overall growing season warming of 1.0 to 2.2 °C. Significant increases in the heat accumulation indices WI and HI (e.g., by 11.24 units per year and by 11.92 per year, respectively, at Priorat) were mostly driven by increases in maximum temperature. These climatic changes have shown moderate to strong relations with vine and wine parameters, including earlier bloom, veraison and consequently earlier harvest dates. Across all the examined varieties (Macabeo, Xarello, Chardonnay, Parellada, and Pinot Noir), bloom and veraison were related to temperature the most, revealing negative correlations. In the DO Costers del Segre, for example, during growing seasons with warmer minimum temperatures, veraison of the Parellada variety occurred earliest (–4.1 days per 1 °C, from 1996 to 2006). During warmer growing seasons in the same region, the Chardonnay variety displayed significantly earlier harvests (–5.3 days per 1 °C, from 1997 to 2006). In the Penedès region, veraison and harvest data for the Macabeo, Parellada, and Xarello varieties, revealed advancements of 3 to 7 days per 1 °C of the growing season's warming from 1996–2006. The researchers also reported that precipitation from the bloom to veraison period had declined significantly for all 3 sites averaging –0.83 mm per year, which indicated potential soil moisture stress during this critical growth stage. In fact, high water deficits have been observed in the studied regions in the previous 10 years of the study (1998–2008), with precipitation providing approximately only 25–30% of the water demands from blooming to veraison. The results of a shorter-term analysis conducted on crop evapotranspiration

(ETc), describe a current increase in the water demands by 6% to 14% per 1 °C of growing season warming.

Similarly, Camps and Ramos (2012) [74] observed increases in the average growing season temperatures over the 14 year period (1996–2009) in three locations (Vilafranca del Penedès, Sant Sadurni d'Anoia and Sant Martí Sarroca) of the Penedès region (north-eastern Spain). For the Vilafranca del Penedès, in particular, these increases were greater (0.11 °C per year) of the respective values (0.04 °C per year) during the previous decades (1960s–2000s). These increases were attributed mainly to the maximum temperatures' and to the extreme heat's (number of days with temperatures exceeding 30 °C) incidence increase. Furthermore, it was shown that in the last decade of the study, the WI index had increased to about 2100 degree days as a result of the temperature rise, compared to the respective value (approx. mean value of 2015 days) estimated during the years 1960–2009. The increasing trends in the average growing season temperatures were significantly correlated with the continuous advancement of the dates on which harvests started and ended and ranged between −0.7 and −1.1 days per year. Over the last 14 years of the study, a mean date of 7 September, which represented an advance of approximately 12 days, on average, was identified for the examined Macabeo, Xarello, Parellada, and Subirant Parent varieties. The greatest impacts of warming with ratios of up to 12 days advancements of harvest per 1 °C increase were found at Vilafranca del Penedès for the Parellada and Macabeo varieties, while for other locations and varieties, the respective advancements ranged from 4 to 6 days per 1 °C increase.

By using estimations on phenological events from both climatic and phenological observations at the Upper Moselle valley-region (southern border between Luxembourg and Germany), Urhausen et al. (2011) [137] concluded on the receding of the phenological events of the examined varieties (Auxerrois, Elbling, Pinot Blanc, Pinot Gris, Riesling, Rivaner and Traminer). This was attributed to the elevated temperatures depicted in the area for the period 1951–2005. The almost 2-week advancements of budburst and flowering (earlier timing by approximately 2 days per decade) were related to the general increasing warming trends depicted in the area, which are comparable to the global warming rate of the previous 25 years. More precisely, the annual mean maximum temperature in this region has increased by 0.7 °C per decade since 1980, while mean and mean minimum temperatures display positive trends of 0.2 °C per decade since 1951.

Bock et al. (2011) [127] evaluated the CC effects on white grapevines cultivated in Würzburg—Lower Franconia (southern Germany) using long-term reference vineyard observations (1948–2010). They revealed the tendency towards the earlier occurrence of phenophases accompanied by shorter phenological intervals. These phenomena were driven majorly by increases in the mean maximum temperature, especially during the growing season. For example, the timing of full flowering was influenced by the mean maximum temperature from April to June. An increase of 1 °C during this period resulted in the advancement of full flowering by approximately 6 days. The timing of veraison was also highly responsive to temperature. Silvaner variety was the most responsive, given the advancing of veraison by 9 days with an increase of 1 °C from April to May. In general, the average dates for full flowering were shown to have advanced by 3 to 4 days per decade, while veraison revealed the most robust trend in time, given its advancement approximately by 4 to 6 days per decade.

Koch and Oehl (2018) [138] reviewed temperature and rainfall data recorded annually over a 40-year timeframe (1975–2015) in Hainfeld within the wine-growing region of Palatinate (southwestern Germany). The researchers correlated these data with grapevine growth parameters of four white wine varieties (Pinot Gris, Riesling, Silvaner and Müller—Thurgau) and the red wine variety Pinot Noir. They concluded that the overall CC in Hainfeld described by the increase in the mean annual temperature by 2.1 °C since 1975 (mean of the annual minimum and maximum temperatures' increase by 0.9 °C and 3.4 °C, respectively), consists of the main driver for the significantly earlier bud break, onset of flowering and veraison. It was shown that since the 1970s, bud break, flowering and veraison occur earlier by 11–15, 18–22 and 16–22 days, respectively, while harvest dates have demonstrated advancements of 25–40 days. Consequent to the temperature rise, the HI was also shown to have increased from 1685 to 2063 units. According to the authors' interpretation of the HI rise, CC may be already favouring the cultivation of grape varieties rarely grown so far in temperate zones and that are more suited to warmer Mediterranean climates (e.g., Cabernet Sauvignon, Syrah and Tempranillo).

According to Karvonen (2020) [139], the appeared rise in annual air temperature has significantly accelerated the growth cycle of grapevines in the cool-cold growth zone of Southern Finland since the beginning of 2000 for two consecutive decades. During 2010–2019, the mean annual temperature in the Helsinki region rose by 0.4 °C compared to the respective mean of 2000–2009. This warming has led to the shortening of the growth cycle (from budbreak to harvest) of the Rondo variety by 11 days on average. The average beginning of harvest has been sped up by 6 days, indicating a significantly sooner occurrence of harvest. A 21-day maximum advancement of harvest has been reached between the years examined. The mean length of the growing seasons in the period 2010–2019 was only 1 day longer than the respective mean in 2000–2009. It was concluded that even during these short two decades, the observed small upward trend in the climate warming significantly advanced the growth cycle of the Rondo variety in the studied region.

According to Baduca Campeanu et al. (2012) [140], the annual mean temperature in Oltenia (southwestern Romania) has increased between 0.2 °C and 0.4 °C in all of the studied areas. For example, an increase of 0.2 °C has been demonstrated for the Sâmbureşti vineyard over the previous 50 years and of 0.3 °C for the Vânju Mare and Dealurile Craiovei vineyards over the previous 60 years, with the warmest years shown since the 1990s. The observed warming has impacted changes in the Romanian viticulture regarding the precociousness of the vegetation cycle of the vine. Results have shown that, in the first decade of the 21st century, the grapes are reaching their absolute maturity by approximately 10 to 15 days earlier than in previous decades (the 1950s and 1960s). The researchers characteristically state that "...harvest in all vineyards in Oltenia today ends when from 1950 to 1960 the harvest was just beginning and over 100 years ago when the harvest had even not started yet".

Evaluation experiments conducted by Lisek (2008) [141] during the years 1986–2007 proved that climatic changes and especially the increase in the annual growing season temperature are favourable to vine growing in Skierniewice (central Poland). Results showed that the development of the Polish winemaking is greatly favoured by CC, given that the average growing season temperature has exhibited an upward trend (approximately 0.5 °C per decade). The warm periods have been prolonged, the winters have become milder and the transitional periods have been shortened. The observed overall warming has enabled thus the cultivation of early and very early varieties or varieties sensitive to low temperatures. It was revealed that, on average, the beginning of bud swelling, blooming and fruit ripening in the years 2005–2007 occurred 12 days earlier for the studied varieties (Perl of Csaba, Seneca, Aurora, Swenson Red, Edelweiss, Chasselas Dore, Steuben) compared with the respective occurrences during the period 1987–1989.

Kovács et al. (2018) [142] examined the phenological response of grapevine to CC in the Sopron and Zala regions (western Carpathian Basin, northwestern Hungary). During the previous 30 years of the study (1986–2015), climate data have shown that the growing season temperatures have risen by almost 1.2 °C, the number of intense heat days (with maximum temperatures over 35 °C) and hot days (with maximum temperatures over 30 °C) has increased approximately by 250–300%. On the contrary, the growing season precipitation has declined by 21%. With respect to the previous 30-year period (1956–1985), the annual growth cycle of grapevines has been shifted significantly, given that budbreak, flowering, and veraison have advanced, respectively, nearly by 8, 7 and 8 days, and the harvest occurs earlier by 11 days. Furthermore, phenological intervals have been shortened, given that the time between budbreak and flowering has been reduced by 4.5 days. It is characteristic that in the previous 10–15 years of the study, the cultivation of warmth-demanding grape varieties has increased by 35%.

Phenology–temperature relationships have been examined by Ruml et al. (2016) [143] for the region of Sremski Karlovci in the province of Vojvodina (northern Serbia). Linear trends for the period 1986–2011 indicated that temperature warming has resulted in the significant advancement of all phenological stages, except budburst. Significant increases in the mean annual and growing season mean maximum and minimum temperatures by 0.08 °C per year were shown for the period (1981–2007), along with the rise of the calculated GDD by 12.0 units per year. The detected averaged trends, across all cultivars, for the outset of flowering, veraison and of the timing of harvest were −0.4, −0.7 and −0.6 days per year, respectively. It was demonstrated that a 1 °C increase in the most impactive temperature variable throughout the most relevant periods for the onset of phenophases led to advancements of budburst, flowering, veraison and of harvest by 3.6, 3.1, 5.2 and 7.4 days, respectively.

Ivanišević et al. (2019) [144] compared the recorded phenological phases of grapevine cultivars as impacted by the climate in two different periods (1986–1998 and 2013–2018) in Vojvodina (northern Serbia). The authors concluded that in recent decades there has been a connection of the changes in the timing of phenology, particularly with the observed temperature increase. Compared to the earlier period (1986–1998), the average monthly temperatures were found to be higher in more recent years (2013–2018). Precipitation also has displayed increases in almost all months, with May being mostly affected (precipitation amount in 2013–2018 was almost twice higher than 1986–1998). The earlier occurrence of all phenological phases in the studied red (Cabernet Sauvignon, Merlot, Pinot Noir, Prokupac, Probus) and white (Chardonnay, Muscat Ottonel, Riesling Italico, Smederevka and Petra) cultivars for 2013–2018, reflected the higher temperature warming during this period compared to previous years. It was shown that flowering had been shifted by 10 days, and in the previous six years of the study, the interval between flowering and veraison had become shorter. By comparing the relative interval for all cultivars, it was shown that the biggest decrease by 7 days was observed in Merlot. The international cultivars were more impacted by CC compared to the local cultivars. For example, the beginning of veraison for Petra (local cultivar) occurs 9 days earlier, compared to the respective earlier occurrence by 17 days for Merlot (international cultivar).

Estimation of the impact of CC on the grapevine's growth cycle in Styria (northeastern Slovenia) for the time period of 1950–2009 has shown a significant impact on the timing of harvest and on the duration of the growing season. It was found that, particularly after 1980, the mean annual and seasonal temperatures have significantly increased by nearly 0.06 °C per year. The average warming rates of the growing season have been driven especially by changes in maximum temperatures and particularly by significant increases in the number of days characterised by temperatures exceeding 30 °C. Under the recorded CC, the shortening of the growing season by 12 to 27 days for all the varieties under investigation (White Riesling, Welschriesling, Sauvignon Blanc, Bouvier, Müller Thurgau, Pinot Gris and Muscat Blanc), has been reported. Between 1980 and 2009, the harvest dates of all the varieties analysed have been shifted from October to September, and this has been attributed to the significant warming trends in the growing season [145,146].

Bernáth et al. (2021) [147] evaluated the influence of warming on the onset of the grapevine's phenophases and the length of the interphase intervals at the locality of Dolné Plachtince (southern Slovakia). Results were based on climatic and phenological data observed during a 34-year period (1985 to 2018). Over the last 10 years, an increase in the average annual temperature of 1.4 °C, and the average growing season temperature of 1.5 °C was assessed. The calculated bioclimatic indices (e.g., GDD and HI) showed significant tendencies of increase, given that the highest values were recorded in 2018 and the lowest values in 1991 (1646.7 vs. 1155.9 and 2477.5 vs. 1705 units, respectively, for GDD and HI). After comparison of the last 10 years (from 2009 to 2018) with the first 10-year period (from 1985 to 1994), it was concluded that budburst in the Pinot Blanc and

Welschriesling varieties is onset by 5 and 7 days earlier, respectively. The earlier onset of flowering in Pinot Blanc by 7 days and in Welschriesling by 10 days was also indicative of the impact of the temperature rise during the more recent period. Furthermore, compared to the 1985–1994 period, the beginning of berry softening during veraison was found to take place 18 days earlier in both varieties. There was also a relatively light trend for the decrease in the interphase between the end of flowering and maturation by 8 to 9 days. On the contrary, both varieties displayed a moderately strong trend for the lengthening of the interval between berry softening and harvest by 7 to 9 days, enabling thus the production of higher quality grapes in cooler regions. Both varieties also displayed earlier harvests by 8 to 10 days on average.

Koufos et al. (2014) [148] analysed the characteristics and trends in the climate parameters in Greece as well as their relationship with viticulture for eight important wine-producing areas (Limnos, Samos, Santorini, Anchialos, Pyrgos, Rodos, Nemea, and Naousa) and local varieties. The majority of the growing season temperature-related parameters (e.g., daily observations of mean, maximum and minimum temperature, GDD) have exhibited significant positive trends across most of the studied locations from 1974 to 2010 (period consisting of varying time periods of the climatic data for each area examined). For this period, significant earlier harvests have been mainly induced by changes in minimum and maximum temperatures. For example, in Limnos, Samos and Santorini islands, harvest has advanced by 0.31 to 0.55 days per year, while in the mainland locations of Anchialos and Pyrgos, harvest has occurred earlier by 0.35 and 0.77 days per year, respectively. The observed occurrence of the harvest in Greece has been approximately 8 to 18 days earlier over the previous 20 to 40 years of the study. Moreover, less sensitivity to CC was shown for areas with late-ripening varieties' cultivation.

In a relevant later study, Koufos et al. (2020) [149] investigated the relationships between air temperature and harvest dates of both international and indigenous winegrape varieties (e.g., Malagouzia, Moschofilero, Agiorgitiko, Muscat Blanc, Merlot, Mavrodaphni) grown in major wine-producing regions in Greece (e.g., Samos, Crete, Drama, Tripoli, Limnos, Santorini, Nemea, etc.). Trend analysis showed that during the last four decades (years between 1974 and 2017 which include the varying time periods of the data), harvest dates had shifted earlier due to the warmer conditions, mainly driven by the increase in the mean daily maximum temperature, formed, in most cases, particularly during the period of ripening. It is characteristic that the warming rate during the ripening period was +0.09 °C higher than the respective rate during the period from March to July. In most cases, significant negative relationships between the date of harvest and mean maximum temperatures during ripening were shown. Over all varieties and regions, harvest dates averaged 11 days earlier over the different time periods of the data and exhibited an earlier occurrence of 5 days per 1 °C increase. The white varieties were slightly more sensitive under the warmer conditions (−5.21 days per 1 °C) compared to the red varieties (−4.78 days per 1 °C). In addition, the early ripening varieties were most sensitive with harvest advancement by nearly 7 days per 1 °C, followed by the late (−4.67 days per 1 °C) and mid ripening varieties (−3.81 days per 1 °C). The international varieties were more sensitive to the warmer ripening periods compared to the indigenous varieties and thus responded with higher advancements (−5.53 days per 1 °C vs. −4.38 days per 1 °C). Overall, independently of the varieties' characteristics, harvest commenced significantly earlier by −0.76 days per year.

3.2. Observed CC and Its Impact on Quality

Duchêne and Schneider (2005) [71] demonstrated that over the previous 30 years, the potential alcohol level of Riesling grapes in Alsace (eastern France) had increased by 2.5% (by volume or *v/v*). This increase was highly correlated to earlier phenological events and significantly higher temperatures during ripening. The significant increases in temperature by almost 2 °C over the examined period were found as responsible for the advancement of phenophases placing ripening under a warmer regime. The potential alcoholic strength between 1973 and 2003 has shown an increase from the mean value of 9.34% vol. for the 1973–1990 time period to 10.58% vol. for the subsequent period 1991–2003, with the highest value of 11.8% vol. being attained in the exceptionally hot year 2003. It was evidenced that the increasingly higher sugar content of the grapes may eventually render them less aromatic, which constitutes a detrimental consequence concerning their quality potential.

Laget et al. (2008) [130] performed an analysis of quality parameters at the Château la Voulte Gasparet (located in the Hérault department of southern France) between 1950 and 2006 in relation to CC. The increasing temperature trends mainly after 1980 (mean annual temperatures increase of 1.3 °C between 1980 and 2006) were linked to the higher concentrations of sugars at harvest by up to 1.5% potential alcohol. Between 1986 and 2007, it was demonstrated that there had been a constant increase in the berries' sugar concentration at harvest. For the 10-year period 1986–1996 the average potential alcohol % volume was 12.78% as compared to 13.53% for the subsequent period 1997–2007. Impacts on other oenological parameters that are linked to the temperature increase were also demonstrated. The researchers refer to an increase in pH from a mean value of 3.55 for the period 1984–1996, to the value of 3.66 for the period 1997–2006 and a decrease in titratable acidity from 3.72 to 3.38 g per litre H_2SO_4, between 1984 and 1996, and 1997 and 2006, respectively).

Climatic impacts estimated by Lereboullet et al. (2014) [150] in the wine-producing area Côtes-du-Roussillon-Villages near Perpignan (southern France) between 2001 and 2010 have been described as adverse effects on the quality of grapes and wine. From climatic data covering an almost ninety-year-old time frame (1925–2010), an increase in the growing season mean temperature by 0.076 °C per year for the most recent study period of 1981 to 2010 was detected. The observed warming was driven mainly by increases in minimum temperatures. Wine producers reported incomplete phenolic maturation and inconsistency between the high accumulation of sugars and the reduction in acidity in the berries, inducing the high alcoholization of the wines. The aforementioned phenomena have been attributed to the continuous increase in the growing season temperatures and the summer temperature extremes since the mid-1980s.

Similarly, research conducted by Neethling et al. (2012) [131] for the period 1960–2010 showed significant increasing trends in the sugar levels and decreasing trends in the acid concentrations (in titratable acidity) at harvest of six white and red winegrape varieties cultivated in the Loire Valley (northwestern France). These changes in berry composition were notably affected by the significant increases in the growing season's mean temperature (by 1.3 to 1.8 °C). As demonstrated, the higher number of days with optimum temperatures occurring during the growing season was shown to have favoured grapevine development and the sugar concentration in the grapes. In general, the results illustrated that the climate variables were the main drivers of the sugar concentration's and titratable acidity's variations. It is underlined that since 1970 in Chinon, 75% and 67% of the Cabernet Franc's acidity and sugar levels' variability, respectively, were explained by climate variables. Due to the high sugar content of the grapes in the previous decades, the wines' ethanol content was found to be increased accordingly. A large number of wines that contained 11–12% vol. ethanol in the 1980s demonstrated increases of about 13–14% vol. It was also commented that the higher levels of potential alcohol associated with the reduced titratable acidity could have adverse impacts on the compositional ratio within the maturing grape, resulting in unbalanced wines and quality degradation.

Teslić et al. (2018) [126] assessed the trend in CC and its impact on grape production and wine composition for seven wineries located in the "Romagna Sangiovese" appellation area (northern Italy). The study over 60 years (from 1953 to 2013) revealed significant increasing trends in the growing season temperature. More precisely, significant increases of 0.04, 0.03 and 0.02 °C per year, with total trends estimated as 2.20, 1.65, and 1.40 °C, respectively, for the maximum, mean, and minimum temperatures were demonstrated. Trends during the growing season period were also shown for the GDD and HI, which exhibited increases of 5.88 and 6.1 units per year, respectively. Decreasing trends were found for the same period for precipitation with an annually and a total trend decrease of 1.94 mm and 118.16 mm, respectively. The reduction in precipitation showed a higher correlation with the increasing potential alcohol content in wines with respect to the rising temperatures (the Dry Spell Index: DSI displayed significant correlations with potential alcohol which were higher compared with the HI). The alcohol content of the examined wines (Sangiovese) over the studied 12-year period (from 2001 to 2012) displayed a significant increase of 0.83% (v/v) over the total period with an increasing annual trend of 0.07% (v/v).

Long-term data (1995–2015) for the berry quality collected in Orvieto in the Umbria region (central Italy) were correlated to representative bioclimatic indices by Biasi et al. (2019) [136]. The results highlighted the increase in the annual and of the growing season mean temperatures. Both WI and HI in grapevine growing areas exhibited a gradual increase. With reference to the increasing number of extremely hot days (with maximum temperature over 30 °C) which characterised the ripening period, the examined white varieties revealed a linear reduction in the titratable acidity (TA) of the berries. All the examined red grape varieties displayed varying trends for sugar accumulation expressed as total soluble solids (TSS) and total TA. In particular, the international varieties Sangiovese and Cabernet Sauvignon, showed a distinct trend to the postponement of the harvest date and of the TSS reduction. On the contrary, the Cabernet Franc and Merlot varieties, indeed, anticipated harvest time and displayed an increase in the TSS accumulation. For the autochthonous Aleatico and Grechetto di Orvieto varieties, no significant trend was identified.

Ramos et al. (2008) [73] highlighted the favouring of wine quality by the higher ripening diurnal temperature ranges displayed in three traditional viticultural regions (Alt Penedès, Priorat, and Segrià) of northeastern Spain, for the time period 1967–2005. The vintage wine quality ranks for the Priorat region's red wines, in particular, exhibited the most significant relation to the ripening period's thermal conditions. More precisely, a greater diurnal temperature range (DTR: maximum temperature–minimum temperature) prevailing during August and September has induced higher quality levels of the red wine. Specifically, it was demonstrated that a +1 °C increase in the DTR resulted in a 0.4 rating point increase on a 1–5 scale (the ranks represented an overall assessment and were given a "poor" to "excellent" characterisation coded 1 to 5 for analysis). Similar outcomes were shown for the Penedès region, despite the fact that the quality ranks for the white wine, compared with the respective ranks for the red wine, were less significantly related to the DTR. Given that the increases in maximum temperature during ripening may also induce higher vine stress, increased water demand and lower product quality, it was underlined that increases in the DTR may not necessarily imply wine quality.

Urhausen et al. (2011) [137] concluded the contribution of the CC influences on grape must at harvest at the Upper Moselle valley region located across the southern border between Luxembourg and Germany. The general increasing warming trends occurring during the studied 55-year period (1951–2005) may be compared to the global warming rate of the previous 25 years of the study. These trends have altered typical grape must characteristics. Since 1980, the annual mean maximum temperature has increased by 0.7 °C per decade, while since 1951, mean and mean minimum temperatures have displayed positive trends of 0.2 °C per decade. The researchers showed an example of the must density and acidity for the Riesling variety over the whole period between 1965 and 2005. The former has increased by 0.3 ± 0.2 °Oe (see Degree Oechsle in Appendix A) and the latter has decreased by 0.096 ± 0.069 g per litre. This behaviour of wine quality was found to be similar to the other vine varieties studied (e.g., Auxerrois, Elbling, Rivaner, Traminer).

Schultz and Jones (2010) [151] have exploited a relatively unique, almost 80-year-old data set from Schloß Johannisberg in the German Rheingau region (southwestern Germany). This data set consisted of mean growing season temperature and grapes' total acidity (malic and tartaric acid) values going back to at least 1932. Their study showed a clear negative correlation between total acidity at harvest and seasonal mean temperature. In particular, the substantial decrease in acidity from the 1980s onwards was linked to a significant increase in the growing season mean temperature. Furthermore, this correlation was found to be stronger than with any other temperature data of parts or individual months of the growing season.

Bock et al. (2011) [127] highlighted the potential loss of the Lower Franconian wine's traditional character due to the earlier maturity of the grapes in Würzburg (southern Germany). Under warmer seasons from 1948 to 2010, grapes were characterised by a greater ripening potential that consequently promoted the unbalanced ratio of the sugar and acid content. Composition characteristics were significantly influenced by the increasing trends in the maximum temperatures, especially during the growing season. The mean sugar content at harvest averaged 80.3 °Oe (between 1950 and 2010) and exhibited a very significant upward decadal trend of 2.4 °Oe with a significant dependence on the pre-flowering (April and May) and pre-harvest (August and September) temperature. Furthermore, no significant trend was displayed for the mean total acid content between 1960 and 2010, which averaged 8.72 g per litre.

By analysing longer-term data (1805–2010) on must sugar content and its relation to temperature evolution in the same area, Bock et al. (2013) [152] confirmed the association between increased mean monthly temperatures and higher must sugar content. From 1805 to 2010, the mean annual temperatures averaged across the country have increased by 1.44 °C. Significant relations between must sugar content and the mean temperatures of the pre-flowering and pre-harvest months (April, July and August) have been revealed. Overall, 38% of the increase in must sugar was justified by the warmer growing season temperatures. More specifically, temperatures during pre-flowering (April) and pre-harvest (July and August) were linked to the higher values of the sugar content. An average of 90.4 °Oe with a significant decadal increase of nearly 3.3 °Oe resulted for the entire observation period. In contrast, in recent decades (1962–2010), the respective values were higher, given an average of 92.6 °Oe and a highly significant increase of 8.3 °Oe per decade.

Forty-year period temperature and rainfall data (1975–2015) measurements were conducted by Koch and Oehl (2018) [138] "on-winery" in Hainfeld (Southern Palatinate, southwestern Germany) and were correlated with the grape sugar concentrations of four white grapevine varieties (Pinot Gris, Riesling, Silvaner and Müller-Thurgau) and the red grapevine variety Pinot Noir. The mean annual minimum and maximum air temperatures were found to have risen by approximately 0.9 °C, and by 3.4 °C, respectively, resulting in an average increase in the mean annual temperature by 2.1 °C between 1975 and 2015. Most of the studied varieties (four of the five) appeared to have responded to the temperature increase by producing higher juice sugar concentration and, consequently, a superior wine. Between 1975 and 2015, an average increase in juice density of approximately 9–17 °Oe for the tested varieties was obtained. Pinot Gris exhibited the highest sugar concentrations among the white varieties and was unaffected throughout time. On the contrary, the highest increase in sugar concentrations since 1991 was shown for the red variety Pinot Noir, thus being especially favoured by the CC occurring in Palatinate.

Baduca Campeanu et al. (2012) [140] attributed the alterations in the ripening process of the grapes to the overall increasing temperature trends occurring in southwestern Romania since the 1960s. Specifically, the annual mean temperature in Oltenia has increased between 0.2 °C and 0.4 °C in all of the studied areas. Given the advancement of all phenological phases due to temperature warming (and therefore, the added heat and light during the grapevine ripening period), significant changes have occurred in the physiological processes regarding grape composition. The researchers reported the accumulation of higher quantities of sugars by 12 to 20 g per litre and the decreases in the total acidity at absolute maturity by 0.75 to 1.8 g per litre of tartaric acid overall the studied vine cultivars. Furthermore, they emphasized the different impacts of such changes between the red (Cabernet Sauvignon and Merlot) and white (Sauvignon and Fetească Albă) varieties. The higher concentrations of sugars and anthocyanins in the grapes (over 100 mg per kg increased content) have been favouring the quality of the red cultivars. However, the decreased acidity has negatively influenced the sensory and compositional balance of the white wines, leading thus to extension limitations of the white cultivars' culture.

Research findings for the time period of 1980–2009 in Styria (northeastern Slovenia) show that harvest has advanced into a warmer part of the season. The grape ripening occurring under warmer conditions has indicated an increase in the sugar levels and a decrease in the total acidity content of the berries. This impact has been considered explicitly as a consequence of higher temperatures (e.g., strong correlations between the decreasing total acidity and increasing HI for all the studied varieties) occurring during the growth period and ripening of the grape berries. It is characteristic that in recent years grapes come to maturity at temperatures which are nearly 2 °C higher than 30 years ago [145,146].

Koufos et al. (2020) [149] investigated the relationships between the air temperature and the grapes' chemical composition produced in many Greek wine regions during the years 2000–2017. Estimations of the alcohol (%) and acidity (g per litre) levels revealed that trends in acid (alcohol) levels were negatively (positively) correlated with the rise in the mean daily maximum temperatures of the ripening period. At this period, the warming rate was +0.09 °C higher than the respective rate during the March-July period. It was demonstrated that the potential alcohol at harvest has increased nearly by 0.40% over the varieties examined, with a trend average of 0.06% per year. Additionally, the international varieties have displayed a slightly higher sensitivity to the warmer conditions during ripening with a trend of 0.24% per 1 °C in contrast with the indigenous varieties, which showed a respective trend of 0.17% per 1 °C. In addition, the white varieties displayed a tendency for higher average acidity compared to the red varieties (5.0 g per litre vs. 4.4 g per litre). Furthermore, the early maturing varieties have averaged 5.0 g per litre acidity at harvest, followed in order by the later maturing varieties with 4.9 g per litre and the mid maturing varieties with the lowest average acidity of 3.9 g per litre.

3.3. Observed CC and Its Impact on Production-Yield

According to Lereboullet et al. (2014) [150] the observed CC between the years 1925 and 2010 in the wine-producing area of Côtes-du-Roussillon-Villages (southern France) is described by the continuous increase in the growing season temperatures and of the summer temperature extremes. Seasonal precipitation patterns display disturbances, given a particular decreasing trend in the summer rainfall of –7.5 mm per decade (between 1931 and 2010) and the autumn rainfall (e.g., 173.9 mm for 1991–2010 vs. 235.8 mm for 1951–1970). These changes have directly negatively impacted viticultural yields, culminating in the 2001–2010 decade as among the lowest in France and, in some instances, below profitability.

Teslić et al. (2018) [126] assessed the CC trend over the last 61 years (1953–2013) in the Romagna Sangiovese area (northern Italy) and its effect on grape production. Total trends found for the maximum, mean, and minimum temperatures were estimated as 2.20, 1.65, and 1.40 °C, respectively. Furthermore, a 118.16 mm total trend decrease was found for precipitation during the growing season. In addition, HI, and GDD showed a total trend of 358.62 and 371.98 units during the studied period, respectively. Approximately in the 1980s, the HI trend shifted the examined area (according to the index' classification) from the "temperate/warm temperate" to the "warm temperate/warm" grape-growing region. Grape production, thus, has shown a significant increasing trend of 33.49 tons per year and 1038.07 total tons during the 31-year period from 1982 to 2012. The authors commented that these results indicate that even if detected in the area of investigation, temperature increase may positively influence crop load to some degree due to the potentially detrimental effect of thermal stress on the grapevine's photosynthetic process.

In a recent study, Gentilucci et al. (2020) [153] have estimated the change in the mean temperatures over the past 50 years in the Marche region (Adriatic coast of Central Italy) through the evaluation of three climatological standard normals (1971–2000; 1981–2010; 1991–2020). The relationship between the variation in the production quantity data of wine grapes and the changes in mean temperature was also examined. The analysis demonstrated a rise in the annual mean temperatures from the past to the present with a higher increase of more than 0.5 °C between 1971 and 1990, and 2001 and 2020 and a rise by 1.2 °C of the maximum values (an indication of an increase in extreme temperatures). The excellent inverse correlation between production and temperature was demonstrated, given that wine grape production decreased with the rise in temperatures in each climatological standard average period. The data of the wine grape production amounted to 10.23, 9.84 and 9.21 t per ha on average for the 1971–2000, 1981–2010 and 1991–2020 period, respectively. There was a good correlation between the increase in temperatures from the preceding to the subsequent period and the reduction in the production of wine grapes, underlying thus the problems related to warmer temperatures.

Ramos et al. (2008) [73] revealed a typical reduction in production experienced from 1952 to 2006 in the warmest vintages of the Alt Penedès, Priorat, and Segrià regions (northeastern Spain). Lower yields (hl) for the 1994–2006 period of the main white varieties were typically seen in the warmest years, as shown in relation to the calculated WI (–388,600 hL per 100 WI units). The impact varied given the observed yield reductions of 915, 1420, and 729 kg per ha per 100 WI units for Macabeo, Parellada and Xarello, respectively. Additionally, the researchers demonstrated a strong association between yield reductions and enhanced water stress. It was shown that over the previous 10 years of the study, yield data in Alt Penedès for the Macabeo and the Chardonnay varieties exhibited an average reduction of 200–320 kg per ha. This was attributed to a precipitation decrease of 10 mm from bloom to veraison. In Priorat, data revealed that Grenache yields declined by an average of 130 kg per ha owing to the same decrease in precipitation. The researchers pointed out that the high water deficits that have been detected in the examined regions result in the limited fulfillment of the vines' water requirements. It was underlined that the water demands have increased by 6% to 14% per 1 °C of growing season warming and that precipitation provides approximately 25–30% of water requirements from bloom to veraison.

Similarly, Camps and Ramos (2012) [74] revealed increases in the average growing season temperatures over a five decade period (1960–2009) in three rainfed vineyard locations (Vilafranca del Penedès, Sant Sadurni d'Anoia and Sant Martí Sarroca) of the Penedès region (northeastern Spain). Along with the temperature warming, they also observed significant decreases in the rainfall amounts recorded between the bloom and veraison phenological stages. Therefore, the significant reductions in winegrape yields were attributed to the increased water deficit resulting from the increased tendency for crop evapotranspiration (due to the increased temperature) and the simultaneous lower precipitation regime during the bloom-veraison period (when water requirements are greater). The negative relationship detected between the estimated water deficit and yield during the bloom–veraison period was demonstrated in all the three studied locations for all the analysed varieties (Macabeo, Xarello and Parellada). From the assessments, it was demonstrated that every mm of the water deficit increase has resulted in yield reductions of 20–30 kg per ha.

Based on their research on the climate-induced changes in grapevine production, Bock et al. (2013) [152] have confirmed the relationship between an upward trend in yield (hL per ha) of the Riesling and Silvaner varieties and the increased mean monthly temperatures recorded over a long time period (1805 to 1998) in Franconia (southern Germany). During this time frame, the mean annual temperatures averaged across Germany have increased by 1.44 °C and significant relationships between yield and mean temperatures of the preceding months have been documented. The authors highlighted that in Germany, nearly 15% of the increase in yield had been attributed to warming, given that the yield from 1805 to 2010 has been highly responsive to temperature. In particular, an increase of 1 °C during the months March and May to August increased yield by approximately 12 hL per ha. For the entire investigated period, yield averaged 25.4 hL per ha with a highly significant increase of about 2.5 hL per ha per decade, equating to nearly 51.25 hL per ha over the last 200 years.

Koch and Oehl (2018) [138] conducted measurements of temperature and rainfall data for the time frame of 1975 to 2015 in Hainfeld (southwestern Germany). These measurements were correlated with grapevine juice yields (hL per ha) of the five white varieties Pinot Gris, Riesling, Silvaner, Müller-Thurgau and the red variety Pinot Noir. Over four decades, the mean annual temperature has already increased significantly, by 2.1 °C since 1975. During the investigated period, juice yields have decreased by approximately 15 hL per ha for Pinot Gris, 17 to 30 hL per ha for Pinot Noir, 22 to 25 hL per ha for Riesling, 25 to 41 hL per ha for Silvaner and 35 to 50 hL per ha for Müller-Thurgau.

Along with the earlier occurrence of the phenological stages of bud swelling, blooming and fruit ripening of the studied cultivars in Skierniewice (central Poland), Lisek (2008) [141] also observed increases in yield parameters. These were mainly attributed to the increased growing season mean temperatures, which have displayed an upward trend of approximately 0.5 °C per decade. Specifically, the weight of grape clusters and berries and the fruit extract content of the berries showed increasing trends given their higher values during 2005–2007 compared to the 1980s. For example, an increase in the cluster weight from 68.9 g to 178.7 g and of the soluble solids content from 13.5% to 16.9% for the Chasselas Dore cultivar has been documented.

3.4. Observed CC and Its Impact on Spatiotemporal Characteristics of Viticultural Areas

Nesbitt et al. (2019); (2016) [154,155], have assessed the influence of the observed CC on the development and sustainability of the UK's viticulture. According to their findings, viticulture is the fastest growing agricultural sector. In England and Wales, vineyard hectarage (ha) has increased 250% from 2004 (a year which was characterised by the outset of the production's domination by sparkling wine) to 2017. The average size of the vineyards has also increased from 2.24 ha in 2004 to 4 ha in 2013. According to the authors, the revival of viticulture in the UK is demonstrated by the catalytic impact of CC which has promoted the enhancement of the investors' confidence, the expansion of the sector, the broadening of varietal suitability, and greater prospects. CC is evidenced through the growing season mean temperatures' warming which has been documented during a relatively recent time frame (1954–2013). In fact, growing season mean temperature has steadily been exceeding the 13 °C cool climate viticulture threshold since 1993. Due to this warming, areas of England and Wales are characterised by a growing season mean temperature range of 13–15 °C, which is considered acceptable for cool climate viticulture. The authors underline that over the last 100 years, the mean temperatures in southeast and south-central England have considerably increased, with most of the warmest growing seasons occurring since 2005. In fact, the current growing season temperature in these areas is increasingly similar to the respective values recorded in the French Champagne region during 1961–1990. Thus, relatively recent vineyards are mainly found in southern England (50–52 °N) with those in the southeast (e.g., East and West Sussex, Kent, etc.) and south-central England (e.g., Berkshire, Hampshire, etc.) accounting approximately for 60% of the UK's total vineyard area. Underpinned by the growing season's warming trends, the consecutive establishment of new vineyards cultivated mainly with Pinot Noir and Chardonnay takes place. It is highlighted that the reappearance of viticulture in the UK provides evidence of the crucial role played by the overall direction of CC.

Denmark demonstrates rapid progress in terms of wine production. According to Smith and Bentzen (2011) [156], CC and innovative developments have allowed wine production under cool climate conditions where the growing season's length is limited. Continuous warming has resulted in an increase in the yearly mean temperature in Denmark from 7.78 °C to 8.58 °C between 1961 and 1990, and 1990 and 2011. The observed warming trends along with the introduction of new wine varieties are promising evolutions for the future of wine production in Denmark. The researchers comment that until recently to the period of their study Denmark had not been a wine-producing country primarily due to the prevailing sub-optimal climate conditions. However, an increasing number of entrepreneurs continuously enter the business of wine production. The introduction of grape varieties that are productive and acclimate more efficiently in cool climate areas has enhanced the interest in wine production expansion.

Results on the warming trends observed by Karvonen (2015) [157] in the Helsinki region (southern Finland) have indicated that the annual mean air temperature has increased by 1.1 °C and that the growing season has extended by 27 days from the year 2005 to the year 2014, as compared to the respective levels during the 1971–2000 time period. Greater opportunities to cultivate grapevines capable of harvest in the southernmost regions of Finland have risen. This has been attributed to the fact that the temperature during summer and the length of the growing season have approximated the relative parameters which represented Central Europe over the period 2005–2014. According to the author's findings, the mean growing season length in the Helsinki region has averaged 198 days in the period 2005 to 2014, in six years of which it has exceeded the duration of 200 days. This fact should suffice for the cultivation of some Central European *Vitis vinifera* varieties. The introduction, therefore, of some newly cultivated plant species for experimentation, such as grapevine, in the southern regions of Finland and the other Nordic countries has been feasible, encouraging a growing interest towards viticulture.

According to Maciejczak and Mikiciuk (2019) [158], Polish viticulture today has become one of the most rapidly developing sectors in Europe, as has the production of domestic wine. The revival of viticulture in Poland is favoured primarily by CC (increased growing season air temperature), accompanied by the consumers' preferences, prosperity growth, ecotourism development and value-added food. A current reality in Poland is a distinct, dynamic growth in the amount of farms and vineyard area registered for wine production. From 2009 to 2010 to 2016 to 2017, the industry has significantly grown given the increase in the number of registered farms (from 26 to 155) and in the total vineyard area (from 36.01 to 238.2 ha). The majority of the vineyards are located in the belt of the southern, south-western and south-eastern provinces, in which optimal conditions (e.g., higher temperatures, favourable levels of sunlight, longer growing seasons) prevail. Furthermore, the natural environmental conditions prevailing in these regions enable the cultivation of popular cold tolerant and disease-resistant hybrid grape varieties. Mazurkiewicz-Pizło and Pizło (2018) [159] also refer to the opportunity for the cultivation of thermophilic plants, induced by the relatively recent climate warming in Central and Eastern Europe, including Poland. Specifically, the surface area has been increasing consistently in the Lubuskie Voivodeship (western Poland) and Wielkopolskie Voivodeship (west-central Poland) regions. Official data indicate that the systematic expansion of the Polish vineyards involves the wineries that are producing wine commercially. Therefore, the surface area of the vineyards in Poland is probably higher owing to the numerous unregistered growers consisting of owners of relatively small wineries with limited production. In their research on the rebirth of viticulture in Poland, Pijet-Migoń and Królikowska (2020) [160] conclude that the establishment of new vineyards will be promoted by climate warming. In the last 25 years the average warming rate is characterised as a few times greater compared to the respective rate over the previous 100 years. By considering the data from the National Support Centre for Agriculture, they point out that the number of vineyards involved in the production of commercial wine has already grown nine-fold in just one decade. Specifically, the authors report that only 26 winemakers cultivating a little over than 36 ha of grapevine plantations were registered in 2009, whereas 10 years later (2019), as many as 230 vineyards occupying 395 ha in total existed. By taking into account the aforementioned relative data up to the year 2017 [158] (155 registered farms and a total vineyard area 238.2 ha), it becomes evident that there is a rapid growth of viticultural activity in Poland.

Kovács et al. (2017) [161] report that the significant warming and precipitation reduction that has been detected over the past 30 years in Sopron (northwestern Hungary), has led to the expansion of the total area planted with the wine cultivars that need more warmth (e.g., Merlot, Cabernet Sauvignon, Furmint). Between 1986 and 2015 (compared to previous decades 1956–1985), significant changes were shown in temperature parameters and the calculated bioclimatic indices. Among others, significant increases were shown for the mean annual temperature (by 1.3 °C), the growing season mean temperature (from 16.4 to 17.9 °C), the GDD (from 1120 to 1240 units) and the HI (from 1930 to 2000 units). Decreases in precipitation during the growing season were also displayed, given the smaller values averaging from 598 to 469 mm. Thus, currently, Sopron wine-growing region is characterised by the researchers as one of "the winners" of CC, given that the prevailing climate is becoming more adequate for the growing of warmth-demanding wine grapes. It is noteworthy that in the previous 10–15 years of the study, the cultivation of grapes had already been expanding into new areas, and winemakers have planted 35% more wine grape varieties than in the past.

4. Summary—Conclusions

The analysis of the time series of the last 30 to 60 years has highlighted warming trends in different European regions. Annual mean temperature data have shown a tendency to increase ranging from approximately 1.0 to 2.0 °C, thus depicting a variation depending on the region (e.g., an increase of 0.8 °C in Denmark and of 2.0 °C in southern France) and the time period of the conducted research. Most cases also refer to a significant continuous increase in the average growing season temperature, which is driven by extreme temperatures (increases in the maximum and minimum mean values). Thus, average warming during the growing season ranging from 1.0 to over 2.0 °C (e.g., by 2.3 °C in northern Italy) has been exhibited and mainly attributed to changes in the mean growing season maximum temperature (e.g., average warming of the growing season maximum temperature by 2.0 °C vs. the respective 1.3 °C rises in the minimum values in northwestern France) and in increases in the number of days with temperature exceeding 30 °C. Additionally, decreasing trends have been displayed for the same period for precipitation. The seasonal precipitation patterns have been disrupted, given the decreasing trends observed in most cases during the growing period (e.g., a 118.16 mm total trend decrease in northern Italy) and the more intense precipitation events (e.g., in central Italy). Lower precipitation regimes in rainfed vineyards have promoted higher water deficits during critical growth periods (e.g., increase in crops' water demands in northeastern Spain by 6% to 14% per 1 °C of growing season warming). Across the majority of the studied locations, the observed warming has been accompanied by the exhibited positive trends in the most common calculated indices (e.g., HI, WI, GDD), which are mainly based on air temperature as it has shown to have the strongest impact on the overall performance of crops.

The viticultural sector is strongly controlled by weather and climate and consequently is susceptible to CC. These impacts are mainly described as the advancement of the grapevine's phenological timing, the shifting of harvest, the unbalance of compositional elements in the grape and wine and thus the quality degradation and alteration of the traditional wine styles, the endangerment of established typical varieties and the decrease in grapevine production. However, CC is also exerting an increasingly profound positive influence on viticulture, given the documented increases in yields, the expansion into previously unsuitable areas for grapevine cultivation and the vineyards' rebirth in the northern and central part of the continent. Present tendencies reveal that the northernmost vine-growing regions will benefit from CC, while many traditional wine regions will have to face its consequences.

Overall, both temperature and precipitation contribute to the timing of harvest and product quality, although the temperature is the most influential atmospheric element in wine grape phenology. The warmer conditions developed during the entire growth cycle of the vine and the resulting considerable advancement of the phenophases places the ripening period during a hotter time period, thus resulting in earlier harvests and negative impacts on grape composition.

Observed tendencies towards the earlier onset of the phenological events and the reduction in the growth intervals, which eventually catalyse the occurrence of earlier harvests, have been attributed mainly to the rising temperatures. The cases reviewed point out advancements for budbreak (e.g., by approx. 5–15 days), flowering (e.g., by 7–24 days) and veraison (e.g., by 5–36 days). Significant shortenings of phenological intervals are also highlighted and often refer to the periods between budbreak to bloom (e.g., by up to 18 days), flowering to veraison (e.g., by up to 7 days), flowering to harvest (e.g., by up to 10 days), veraison to harvest (e.g., by up to 6 days) and budburst to harvest (e.g., by up to 25 days). The increasing temperatures recorded in traditional wine regions have resulted in a shorter duration of the growing season, which may exceed the monthly period. As a result, the earlier achievement of harvest is frequently concluded, reaching advancements of up to 40 days. Overall, the reviewed cases demonstrate that phenological rhythms are mainly controlled by air temperature, underlying the significance of investigating this agroclimatic parameter to detect the CC impacts on crops.

As a result of a shorter growing period, ripening occurs under higher temperatures, which negatively impact the quality of grape and wine. The increase in mean temperatures throughout the summer period as the major implication of CC and the different distribution of rainfall over the ripening phase have both induced alterations in the sugar concentrations and the acidic profile of grapes. Overall, higher sugar concentrations (e.g., decadal increasing trend ranging from 2.3 to 4.2 °Oe during the past 30–60 years in Germany) and lower acidity (e.g., decreases by 0.75 to 1.8 g per litre of tartaric acid during a 60-year period in Romania) are demonstrated for grapes. Maturation timing differentiates the acidity levels, given that the early ripening varieties display higher grape acidity levels at harvest compared to the late ripening varieties (e.g., mean acidity of 5.0 vs. 4.9 g per litre over 20 years in Greece). Although broadly linked to higher vintage ratings, earlier maturation impacts the aromatic profiles and the balance between the sugars and acidity in the grapes at harvest, ultimately leading to the production of high wine alcohol levels (e.g., increase of approximately 1% vol. in a 30-year period in France) and, therefore, to the gradual loss of wine typicity (Appendix A). The majority of the European wine regions have been subjected to significant warming trends in recent decades. During the second half of the 20th century, warming has generally upgraded wine quality, especially in the cooler vineyard regions (e.g., Poland). On the other hand, the rising temperature trend has been recognised as an obstacle for wine production owing to the resulting increased heat and drought stress in areas where grapevine is cultivated close to the optimum temperature, such as vineyards in southern Europe (e.g., Greece).

The advent of CC has displayed heterogeneous effects on grapevine viticultural production. Direct negative impacts on viticultural yields have been documented and attributed to the continuous increase in the growing season mean temperature and the disruption of the seasonal precipitation patterns, mostly described as reductions in summer and autumn rainfall. The reviewed research demonstrates a strong association linking yield reduction and enhanced drought stress between critical phenological phases (e.g., bloom to veraison). On the contrary, temperature increase has positively influenced the crop load to some degree, given that the observed increases in yields are significantly correlated to warming.

In terms of the spatiotemporal characteristics of viticultural areas, it is shown that the increase in temperatures has advantaged cold climates in their opportunity to favour the expansion of viticulture. Changes in the limits of the viticulture's spatial expansion are already being observed, given that vineyards are now productive at more polar latitudes (e.g., England and Wales, Denmark, Finland). The continuously growing interest in grapevine cultivation in new regions owing to the general warming trend may also be attributed to the development of new, more low-temperature-resistant grapevine variants.

By comprehending and assessing the opportunities and risks grape growers are likely to face in the upcoming decades, implementing sustainable and quality-oriented viticulture is of paramount importance. Sound and advanced management strategies are vital to minimise the effects of CC and, therefore, maintain wines of high quality, varietal typicity, regional wine identity, respond to changing market conditions, and constitute advantageous investments for viticulturists. By considering the fact that the consumers' tastes are affected by long-lasting traditions and cultural traits that are persistent and very difficult to modify, the urgency to design effective public policies and thus the combination of focused mitigation and adaptation strategies becomes more evident.

Such strategies may include developments in plant technology (e.g., plant material innovations involving the breeding and selection of more resilient rootstocks, varieties and clones with improved climate tolerance and the preservation of genetic diversity). In addition, another strategy is the modification of viticultural techniques for the maintenance of harvest in the Northern Hemisphere's optimal period (end of September or early October). A further strategy is the implementation of irrigation strategies with high consideration of the related effects on water resources and the environment. Furthermore, the relocation of vineyards to more suited areas (from warmer to cooler areas and vice versa) is increasingly considered to be a promising solution. Overall, a central goal of viticultural and policy decisions should be to decrease the risk associated with CC over the next few decades. This is also underpinned by the fact that grapevine is a perennial fruit crop with long productive life and high establishment costs. Thus, the grapevine is a typical example of an agricultural crop that could markedly benefit from substantial knowledge on the recent past risks to inform decisions on vine cultivation location, cultivar selection and management.

The effects of CC on the grapes' production and quality pose a significant challenge for the years to come. Knowledge of CC's impacts on viticulture to this day is of fundamental importance by accounting for the uncertainty of the evolution rate and extent of this phenomenon in the course of time. Despite the fact that grapevines can be adapted to the climate, the already documented geographical heterogeneity in the changes in temperature and precipitation and the expected increased frequency of future extreme events may engender different grapevine responses [18]. Furthermore, as indicated from up to the present, the impact of future CC is expected to be highly heterogeneous across varieties and regions.

The comprehension of the future by looking up to the present arises, therefore, as a very informative necessity but also urgent procedure, considering that the impacts of CC reported in this review imply very important social and economic consequences for the European viticulture industry in which provenance and cultivar are substantial pointers of the products' excellence and typicity. These features certainly highlight the relevance and the mandatory continuation of regional assessments. Data on the already observed impacts of CC can be utilised and incorporated into CC sophisticated and accurate tools to understand better and define the effect of this phenomenon on the environmental sustainability of the viticultural sector in the decades to come.

The undisputed numerous impacts of CC on European viticulture, already brought about over recent years, have considerably increased scientific research. The impact of CC on the grapevine has been intensively studied in different regions underlying the agroclimatic potential under the changing climatic conditions.

The contribution of this review to the CC issue lies in the compilation of a relatively high number of scientific outcomes on the observed impacts of the phenomenon on European viticulture. Future planning involves the extension of our research to explore the impacts of CC on past to present and in the upcoming decades over other crops of substantial socio-economic and nutritional importance by primarily accounting that the ongoing CC adds a significant element of uncertainty.

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Appendix A. Glossary

Agroclimatology: Often also referred to as agricultural climatology, agroclimatology is a field in the interdisciplinary science of agrometeorology, in which principles of climatology are applied to agricultural systems. Its origins relate to the foremost role that climate plays in plant and animal production. Formal references to the terms "agrometeorology" and "agroclimatology" date to the beginning of the twentieth century, but the use of empirical knowledge can be traced back at least 2000 years. Agroclimatology is sometimes used interchangeably with agrometeorology, but the former refers specifically to the interaction between long-term meteorological variables (i.e., climate) and agriculture [162].

Climate: Climate, in a narrow sense, is usually defined as the average weather, or more rigorously, as the statistical description in terms of the mean and variability of relevant quantities over a period of time ranging from months to thousands or millions of years. The classical period for averaging these variables is 30 years, as defined by the World Meteorological Organization (Geneva, Switzerland). The relevant quantities are most often surface variables such as temperature, precipitation and wind. The climate, in the broader sense, is the state, including a statistical description, of the climate system [163].

Climate change (CC): A change in the state of the climate that can be identified (e.g., by using statistical tests) by changes in the mean and/or the variability in its properties and that persists for an extended period, typically decades or longer. CC may be due to natural internal processes, external forces, persistent anthropogenic changes in the atmosphere's composition or in land use [163].

Degree Oechsle (°Oe): measures the relative sweetness of the must (grape juice) and shows how much more 1 litre of must weighs compared to 1 litre of water [164].

Growing season mean (or average) temperature: an estimate of the mean temperatures of all days during the growing season, which refers to the time period of the 1st of April to the 30th of September in the northern hemisphere or of the 1st of October to the 30th of April in the southern hemisphere [165].

Phenology: Defined as a succession of development stages of living beings throughout a season and in relation to the climate. It applies to vegetal matter but also to animals. Phenology constitutes a veritable biological clock for the vines, which is useful when comparing vine parcels at an equivalent development stage [166]. Knowledge of a plant's phenological characteristics is never more important than for *Vitis vinifera* L. grapevines, where the optimum development of quality fruit for wine production is tied to phenological occurrence and timing [70,167].

Phenological phase-stage-event or phenophase: An observable stage or phase in the annual life cycle of a plant or animal that can be defined by a start and endpoint. Phenophases generally have a duration of a few days or weeks. Examples include the period over which newly emerging leaves are visible or the period over which open flowers are present on a plant. The definition of the term "phenophase" has not yet been standardised and varies among scientists. The definition presented here reflects the usage of the term on the USA National Phenology Network (NPN) website [168].

Phenological phases-stages-events or phenophases of grapevine: There are three main grapevine phenological phases commonly considered in the literature [169]: budburst (or bud break), floraison (also referred to as flowering or blooming) and veraison. Budburst marks the beginning of seasonal grapevine growth and resumed physiological activity after a long period of winter dormancy; flowering is crucial for the reproductive cycle, being closely followed by the fruit set stage [170], and veraison initiates the ripening stage change in the colour of the berries, which is tied strictly to wine grape quality attributes [70]. The most well-known notation scales are those of Baggiolini, Eichorn and Lorenz and BBCH (Biologische Bundesanstalt, Bundessortenamt and CHemical industry). Baggiolini describes the stages from A (winter bud) to N (maturity), Eichorn and Lorenz from 1 (winter bud) to 38 (maturity) and BBCH from 00 (winter bud) to 89 (maturity) and 97 (leaf-fall) [166].

Phenological interval: The interval between phenological events. It gives an indication of the overall climate since short intervals between events are associated with optimum conditions that facilitate rapid physiological growth and differentiation [70]. In contrast, long intervals indicate less than ideal climate conditions and delay in growth and maturation [171].

Terroir: "According to OIV (Resolution OIV/VITI 333/2010), terroir is a concept which refers to an area in which collective knowledge of the interactions between the identifiable physical and biological environment and applied viticultural and oenological practices develops, providing distinctive characteristics for the products originating from this area. Terroir includes specific soil, topography, climate, landscape characteristics and biodiversity features" [172].

Wine typicity: a term in wine tasting used to describe the degree to which a wine reflects its varietal origins [127]. It can be defined as a juxtaposition of unique traits that define a class of wines having common aspects of terroir involving biophysical and human dimensions that make the wines recognisable and in theory, unable to be replicated in another territory [173].

Appendix B. Synoptic Description of the Compiled Scientific Outcomes on the Change in Climate and Its Impacts on Grapevine Performance

European Country	Country Region	Years (Time Period of Climatic Data Recording)	Climate and Bioclimate Parameters Change	Impacts on Viticulture	[Reference]
France Italy Spain Germany Slovakia	E(Alsace), NE(Reims), CE (Burgundy), SW (Bordeaux) NE (Conegliano) NW (Valladolid) NW (Pontevedra) W (Geisenheim) S (Dolné Plachtince)	52 years (1952–2004)	(↑) GST (↑) GSTmax (↑) GSTmin (↑) HI (↑) GDD	Earlier phenological events; shorter phenological intervals	Jones et al. (2005) [17]
France	E (Alsace)	30 years (1972–2003)	(↑) Tan (↑) HI (↑) NDT_{10}	Advancement of phenophases; shortening of phenological intervals; earlier harvest/higher sugar content; higher alcoholic strength	Duchêne and Schneider (2005) [71]
France	S (Hérault)	56 years (1950–2006)	(↑) Tan (↑) PET (↑) SR (↑) HI	Advancement of harvest dates/increase in sugar concentrations at harvest; increase in alcoholic content and of pH in wine; decrease in titratable acidity in wine	Laget et al. (2008) [130]
France	NW (Loire Valley)	50 years (1960–2010)	(↑) GST (↑) GSTmax (↑) GSTmin (↑) NDT_{30} (↑) HI, GDD	Earlier harvest dates/Increase in sugar levels; increase in ethanol content; decrease of acid concentration	Neethling et al. (2012) [131]
France	S (Roussillon)	85 years (1925–2010)	(↑) GST (↑) GSTmin (↓) Ps, (↓) Paut	Increase in wine alcoholization/decrease in yields	Lereboullet et al. (2014) [150]

European Country	Country Region	Years (Time Period of Climatic Data Recording)	Climate and Bioclimate Parameters Change	Impacts on Viticulture	[Reference]
France Switzerland		20th c. (1901–2007)	(↑) Tsp, Ts (↓) Psp, (↓) Ps	Earlier harvest	Cook and Wolkovich (2016) [132]
Italy	N (Conegliano in Veneto)	45 years (1964–2009)	(↑) GST (↑) GSTmax, (↑) GSTmin	Earlier phenological events; shorter phenological intervals; earlier harvest	Tomasi et al. (2011) [24]
Italy France	C (Abruzzo) SW (Bordeaux)	35 years (1974–2009)	(↑) GST (↑) DTR (↑) NDT_{30} (↑) AT, HI, NHH	Advancement of harvest dates	Di Lena et al. (2012) [134]
Italy	C (Abruzzo)	40 years (1974–2013)	(↑) Tan (↑) HS, HI, NHH, GDH, GI, HTE	Advancement of harvest dates; shortening of growing season	Di Lena et al. (2019) [133]
Italy	C (Abruzzo)	53 years (1959–2012)	(↑) GST (↑) Pint	Earlier harvest	Di Carlo et al. (2019) [135]
Italy	N (Romagna Sangiovese)	61 years (1953–2013)	(↑) GST (↑) GSTmax (↑) GSTmin (↑) GDD, HI, DSI	Increase in alcohol content in wines/increase in yields	Teslić et al. (2018) [126]
Italy	C (Umbria)	20 years (1995–2015)	(↑) Tan (↑) GST (↑) NDT_{30} (↑) WI, HI, CI	Advanced and delayed harvest dates (dependent on genotype)/reduction in titratable acidity in white berries; decrease or increase in sugar content in red berries (dependent on genotype)	Biasi et al. (2019) [136]
Italy	C (Marche)	50 years (1971–2020)	(↑) Tan (↑) Tan_{max}	Decrease in wine grape production	Gentilucci et al. (2020) [153]
Italy	N (South Tyrol)	25 years (1996–2021)	(↑) Tbud	Earlier harvest	Ferretti et al. (2021) [72]
Spain	NE (Alt Penedès, Priorat, Segrià)	45 years (1952–2006)	(↑) GST (↑) GSTmax (↑) NDT_{30} (↑) DTR (↓) Pbl-vr (↑) ETc (↑) WI, HI	Earlier phenological events; earlier harvest/Increase in wine quality/Decrease in yields	Ramos et al. (2008) [73]
Spain	NE (Vilafranca del Penedès, Sant Sadurni d'Anoia and Sant Martí Sarroca in Penedès)	50 years (1960–2009)	(↑) GST (↑) NDT_{30} (↓) Pbl-vr (↑) ETc (↑) WI	Advancement in harvest dates/Decrease in yields	Camps and Ramos (2012) [74]
Luxembourg–Germany	Upper Moselle or German-Luxembourgian Moselle	55 years (1951–2005)	(↑) Tan (↑) Tan_{max} (↑) Tan_{min}	Earlier phenological events/Increase in must density; decrease in acidity	Urhausen et al. (2011) [137]
Germany	SW (Schloß Johannisberg in Rheingau region)	78 years (1932–2010)	(↑) GST	Decrease in total acidity at harvest	Schultz and Jones (2010) [151]

European Country	Country Region	Years (Time Period of Climatic Data Recording)	Climate and Bioclimate Parameters Change	Impacts on Viticulture	[Reference]
Germany	S (Würzburg–Lower Franconia)	62 years (1948–2010)	(↑) GSTmax	Advancement of phenophases; shortening of phenological intervals/increase in sugar content	Bock et al. (2011) [127]
Germany	S (Würzburg–Lower Franconia)	~2 c. (1805–1998)	(↑) Tmn (↑) Tan	Increase in must sugar content/increase in yields	Bock et al. (2013) [152]
Germany	SW (Hainfeld–Southern Palatinate)	40 years (1975–2015)	(↑) Tan (↑) Tan_{min} (↑) Tan_{max} (↑) HI	Advancement in phenophases; earlier harvest/Increase in juice sugar concentration/decrease in juice yields	Koch and Oehl (2018) [138]
Finland	S (Helsinki)	20 years (2000–2019)	(↑) Tan	Shortening of growth cycle; earlier harvest	Karvonen (2020) [139]
Romania	SW (Oltenia)	60 years (1951–2009)	(↑) Tan	Precociousness of vegetation cycle; advancement of phenological phases; earlier grape maturity; earlier harvest/Increase in sugar content in grapes; decrease in total acidity in grapes	Baduca Campeanu et al. (2012) [140]
Poland	C (Skierniewice)	22 years (1986–2007)	(↑) Tan (↑) GST	Earlier phenological stages/Increase in cluster and berry weight; increase in fruit extract content	Lisek (2008) [141]
Hungary	NW (Sopron)	30 years (1986–2015)	(↑) Tan (↑) GST (↓) GSP (↑) GDD, HI	Extension of total planted area; Increase in cultivated wine varieties	Kovács et al. (2017) [161]
Hungary	NW (Sopron, Zala)	30 years (1986–2015)	(↑) GST (↑)NDT_{30}, (↑)NDT_{35} (↓) GSP	Earlier phenological phases; shortening of phenological intervals; earlier harvest	Kovács et al.(2018) [142]
Serbia	N (Sremski Karlovci)	27 years (1981–2007)	(↑) Tan (↑) GSTmax, GSTmin (↑) GDD	Advancement of phenological stages; earlier harvest	Ruml et al. (2016) [143]
Serbia	N (Vojvodina)	32 years (1986–2018)	(↑) Tmn (↑) Pmn	Earlier phenological stages; shortening of phenological intervals	Ivanišević et al. (2019) [144]
Slovenia	NE (Styria)	60 years (1950–2009)	(↑) Tan (↑) GST (↑) NDT_{30} (↑) HI	Shortening of growing season; earlier maturity; earlier harvest/increase in the sugar levels in berries; decrease in total acidity in berries	Vršič and Vodovnik (2012) [145] Vršič et al. (2014) [146]

European Country	Country Region	Years (Time Period of Climatic Data Recording)	Climate and Bioclimate Parameters Change	Impacts on Viticulture	[Reference]
Slovakia	S (Dolné Plachtince)	34 years (1985–2018)	(↑) Tan (↑) GST (↑) GDD, HI	Earlier onset of phenophases; shortening and lengthening of interphase intervals; advancement of harvest	Bernáth et al. (2021) [147]
Greece	Limnos, Samos, Santorini Anchialos, Pyrgos, Rodos, Nemea, Naousa	36 years (1974–2010)	(↑) GST (↑) GSTmax (↑) GSTmin (↑) GDD	Earlier harvest	Koufos et al. (2014) [148]
Greece	Samos, Crete, Drama, Kavala, Maronia, Tripoli, Chalkidiki, Limnos Naousa, Rodos, Santorini, Nemea, Aigialia, Pyrgos	43 years (1974–2017)	(↑) Td_{max}	Earlier harvest/Increase in alcohol levels; decrease in acidity	Koufos et al. (2020) [149]
UK	England, Wales	70 years (1954–2013)	(↑) GST	Increase in total hectarage; increase in average vineyard size	Nesbitt et al. (2019) [154] Nesbitt et al. (2016) [155]
Denmark		50 years (1961–2011)	(↑) Tan	Increase in interest for wine production expansion	Smith and Bentzen (2011) [156]
Finland	S (Helsinki)	43 years (1971–2014)	(↑) Tan	Growing interest towards viticulture	Karvonen (2015) [157]
Poland		8 years (2009–2017) 10 years (2009–2019)	(↑) GST	Revival of viticulture; growth in the number of grapevine plantations; increase in total vineyard area	Maciejczak and Mikiciuk (2019) [158] Mazurkiewicz-Pizło and Pizło (2018) [159] Pijet-Migoń and Królikowska (2020) [160]

N = North; S = South; E = East; W = West; CE = Central east, SW = Southwest; NE = Northeast; NW = Northwest; C = Central; (↑) = increase; (↓) = decrease; AT = Active Temperature; CI = Cool night Index; DSI = Dry Spell Index; DTR = Diurnal Temperature Range; ETc = crop EvapoTranspiration; GDD = Growing Degree-Days index; GDH = Growing Degree Hours; GI = Gladstone Index; GSP = Growing Season Precipitation; GST = average Growing Season Temperature; GSTmax = average Growing Season maximum Temperature; GSTmin = average Growing Season minimum Temperature; HI = Huglin Index; HS = Heat Summation; HTE = High Thermal Excesses; NDT_{10} = number of days with T > 10 °C; NDT_{25} = number of days with T > 25 °C; NDT_{30} = number of days with T > 30 °C; NDT_{35} = number of days with T > 35 °C; NHH = Normal Heat Hours; Paut = autumn Precipitation; Pbl-vr = Precipitation from bloom to veraison; PET = Potential EvapoTranspiration; Pint = Precipitation intensity; Pmn = mean monthly Precipitation; Ps = summer Precipitation; Psp = spring Precipitation; SR = Solar Radiation; Tan = mean annual temperature; Tan_{max} = mean annual maximum temperature; Tan_{min} =mean annual minimum temperature; Tbud = budding season temperature; Td_{max} = mean daily maximum temperature; Tmn = mean monthly temperature; Ts = summer temperature; Tsp = spring temperature; WI = Winkler Index.

References

1. Brooks, N.; Grist, N.; Brown, K. Development Futures in the Context of Climate Change: Challenging the Present and Learning from the Past. *Dev. Policy Rev.* **2009**, *27*, 741–765. [CrossRef]
2. Core Writing Team; Pachauri, R.K.; Reisinger, A. (Eds.) *IPCC, 2007: Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*; IPCC: Geneva, Switzerland, 2007; p. 104. ISBN 92-9169-122-4.
3. Core Writing Team; Pachauri, R.K.; Meyer, L. (Eds.) *IPCC, 2014: Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*; IPCC: Geneva, Switzerland, 2014; p. 151. ISBN 978-92-9169-143-2.
4. Charalampopoulos, I.; Droulia, F. The Agro-Meteorological Caused Famines as an Evolutionary Factor in the Formation of Civilisation and History: Representative Cases in Europe. *Climate* **2021**, *9*, 5. [CrossRef]
5. Houghton, J.T.; Ding, Y.; Griggs, D.J.; Noguer, N.; van der Linden, P.J.; Dai, X.; Maskell, K.; Johnson, C.A. (Eds.) *IPCC, 2001: Climate Change 2001: The Scientific Basis. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change*; IPCC: Cambridge, UK, 2001; p. 881. ISBN 0521-80767-0.
6. Kostopoulou, E.; Jones, P.D. Assessment of Climate Extremes in the Eastern Mediterranean. *Meteorol. Atmos. Phys.* **2005**, *89*, 69–85. [CrossRef]
7. Perkins-Kirkpatrick, S.E.; Lewis, S.C. Increasing Trends in Regional Heatwaves. *Nat. Commun.* **2020**, *11*, 3357. [CrossRef]
8. Hari, V.; Rakovec, O.; Markonis, Y.; Hanel, M.; Kumar, R. Increased Future Occurrences of the Exceptional 2018–2019 Central European Drought under Global Warming. *Sci. Rep.* **2020**, *10*, 12207. [CrossRef]
9. Zeder, J.; Fischer, E.M. Observed Extreme Precipitation Trends and Scaling in Central Europe. *Weather Clim. Extrem.* **2020**, *29*, 100266. [CrossRef]
10. Harkness, C.; Semenov, M.A.; Areal, F.; Senapati, N.; Trnka, M.; Balek, J.; Bishop, J. Adverse Weather Conditions for UK Wheat Production under Climate Change. *Agric. For. Meteorol.* **2020**, *282–283*, 107862. [CrossRef]
11. Lavalle, C.; Micale, F.; Houston, T.D.; Camia, A.; Hiederer, R.; Lazar, C.; Conte, C.; Amatulli, G.; Genovese, G. Climate Change in Europe. 3. Impact on Agriculture and Forestry. A Review. *Agron. Sustain. Dev.* **2009**, *29*, 433–446. [CrossRef]
12. Jones, G.V. Climate, Grapes, and Wine: Structure and Suitability in a Changing Climate. *Acta Hortic.* **2012**, *931*, 19–28. [CrossRef]
13. Ortiz-Bobea, A.; Ault, T.R.; Carrillo, C.M.; Chambers, R.G.; Lobell, D.B. Anthropogenic Climate Change Has Slowed Global Agricultural Productivity Growth. *Nat. Clim. Chang.* **2021**, *11*, 306–312. [CrossRef]
14. Labriet, M.; Joshi, S.R.; Vielle, M.; Holden, P.B.; Edwards, N.R.; Kanudia, A.; Loulou, R.; Babonneau, F. Worldwide Impacts of Climate Change on Energy for Heating and Cooling. *Mitig. Adapt. Strateg. Glob. Chang.* **2015**, *20*, 1111–1136. [CrossRef]
15. Venäläinen, A.; Lehtonen, I.; Laapas, M.; Ruosteenoja, K.; Tikkanen, O.-P.; Viiri, H.; Ikonen, V.-P.; Peltola, H. Climate Change Induces Multiple Risks to Boreal Forests and Forestry in Finland: A Literature Review. *Glob. Chang. Biol.* **2020**, *26*, 4178–4196. [CrossRef] [PubMed]
16. Dogru, T.; Marchio, E.A.; Bulut, U.; Suess, C. Climate Change: Vulnerability and Resilience of Tourism and the Entire Economy. *Tour. Manag.* **2019**, *72*, 292–305. [CrossRef]
17. Jones, G.V.; Duchêne, E.; Tomasi, D.; Yuste, J.; Braslavska, O.; Schultz, H.; Martinez, C.; Boso, S.; Langellier, F.; Perruchot, C.; et al. Changes in European Winegrape Phenology and Relationships with Climate. In Proceedings of the XIV International GESCO Viticulture Congress, Geisenheim, Germany, 23–27 August 2005; pp. 54–61.
18. Droulia, F.; Charalampopoulos, I. Future Climate Change Impacts on European Viticulture: A Review on Recent Scientific Advances. *Atmosphere* **2021**, *12*, 495. [CrossRef]
19. Jones, G.V.; White, M.A.; Cooper, O.R.; Storchmann, K. Climate Change and Global Wine Quality. *Clim. Chang.* **2005**, *73*, 319–343. [CrossRef]
20. Grassi, F.; Labra, M.; Imazio, S.; Spada, A.; Sgorbati, S.; Scienza, A.; Sala, F. Evidence of a Secondary Grapevine Domestication Centre Detected by SSR Analysis. *Theor. Appl. Genet.* **2003**, *107*, 1315–1320. [CrossRef]
21. Parker, A.K.; García de Cortázar-Atauri, I.; Gény, L.; Spring, J.-L.; Destrac, A.; Schultz, H.; Molitor, D.; Lacombe, T.; Graça, A.; Monamy, C.; et al. Temperature-Based Grapevine Sugar Ripeness Modelling for a Wide Range of *Vitis vinifera* L. Cultivars. *Agric. For. Meteorol.* **2020**, *285–286*, 107902. [CrossRef]
22. Rodrigues, P.; Pedroso, V.; Gonçalves, F.; Reis, S.; Santos, J.A. Temperature-Based Grapevine Ripeness Modeling for Cv. Touriga Nacional and Encruzado in the Dão Wine Region, Portugal. *Agronomy* **2021**, *11*, 1777. [CrossRef]
23. OIV. Statistical Report on World Vitiviniculture. *International Organisation of Vine And Wine: Paris, France.* 2019. Available online: https://www.oiv.int/public/medias/6782/oiv-2019-statistical-report-on-world-vitiviniculture.pdf (accessed on 25 November 2021).
24. Tomasi, D.; Jones, G.V.; Giust, M.; Lovat, L.; Gaiotti, F. Grapevine Phenology and Climate Change: Relationships and Trends in the Veneto Region of Italy for 1964–2009. *Am. J. Enol. Vitic.* **2011**, *62*, 329–339. [CrossRef]
25. Coombe, B.G. Influence of Temperature on Composition and Quality of Grapes. *Acta Hortic.* **1987**, *206*, 23–36. [CrossRef]
26. Keller, M.; Tarara, J.M.; Mills, L.J. Spring Temperatures Alter Reproductive Development in Grapevines. *Aust. J. Grape Wine Res.* **2010**, *16*, 445–454. [CrossRef]

27. Torregrosa, L.; Bigard, A.; Doligez, A.; Lecourieux, D.; Rienth, M.; Luchaire, N.; Pieri, P.; Chatbanyong, R.; Shahood, R.; Farnos, M.; et al. Developmental, Molecular and Genetic Studies on Grapevine Response to Temperature Open Breeding Strategies for Adaptation to Warming. *OENO One* **2017**, *51*, 155–165. [CrossRef]
28. Gil, P.M.; Lobos, P.; Durán, K.; Olguín, J.; Cea, D.; Schaffer, B. Partial Root-Zone Drying Irrigation, Shading, or Mulching Effects on Water Savings, Productivity and Quality of 'Syrah' Grapevines. *Sci. Hortic.* **2018**, *240*, 478–483. [CrossRef]
29. Romić, D.; Karoglan Kontić, J.; Preiner, D.; Romić, M.; Lazarević, B.; Maletić, E.; Ondrašek, G.; Andabaka, Ž.; Bakić Begić, H.; Bubalo Kovačić, M.; et al. Performance of Grapevine Grown on Reclaimed Mediterranean Karst Land: Appearance and Duration of High Temperature Events and Effects of Irrigation. *Agric. Water Manag.* **2020**, *236*, 106166. [CrossRef]
30. Carbone, A.; Quici, L.; Pica, G. The Age Dynamics of Vineyards: Past Trends Affecting the Future. *Wine Econ. Policy* **2019**, *8*, 38–48. [CrossRef]
31. Ramos, M.C.; Martínez de Toda, F. Variability in the Potential Effects of Climate Change on Phenology and on Grape Composition of Tempranillo in Three Zones of the Rioja DOCa (Spain). *Eur. J. Agron.* **2020**, *115*, 126014. [CrossRef]
32. Sadras, V.O.; Moran, M.A. Elevated Temperature Decouples Anthocyanins and Sugars in Berries of Shiraz and Cabernet Franc. *Aust. J. Grape Wine Res.* **2012**, *18*, 115–122. [CrossRef]
33. Gonzalez Antivilo, F.; Paz, R.C.; Echeverria, M.; Keller, M.; Tognetti, J.; Borgo, R.; Roig Juñent, F. Thermal History Parameters Drive Changes in Physiology and Cold Hardiness of Young Grapevine Plants during Winter. *Agric. For. Meteorol.* **2018**, *262*, 227–236. [CrossRef]
34. Buttrose, M.S. Fruitfulness in Grapevines: Effects of Light Intensity and Temperature. *Int. J. Plant Sci.* **1969**, *130*, 166–173. [CrossRef]
35. Greer, D.H.; Weedon, M.M. The Impact of High Temperatures on *Vitis vinifera* Cv. Semillon Grapevine Performance and Berry Ripening. *Front. Plant Sci.* **2013**, *4*, 491. [CrossRef]
36. Keller, M.; Tarara, J.M. Warm Spring Temperatures Induce Persistent Season-Long Changes in Shoot Development in Grapevines. *Ann. Bot.* **2010**, *106*, 131–141. [CrossRef] [PubMed]
37. de Rességuier, L.; Mary, S.; Le Roux, R.; Petitjean, T.; Quénol, H.; van Leeuwen, C. Temperature Variability at Local Scale in the Bordeaux Area. Relations With Environmental Factors and Impact on Vine Phenology. *Front. Plant Sci.* **2020**, *11*, 515. [CrossRef] [PubMed]
38. Amerine, M.A.; Winkler, A.J. Composition and Quality of Musts and Wines of California Grapes. *Hilgardia* **1944**, *15*, 493–675. [CrossRef]
39. Dokoozlian, N.K. Chilling Temperature and Duration Interact on the Budbreak of 'Perlette' Grapevine Cuttings. *Hortscience* **1999**, *34*, 1–3. [CrossRef]
40. Bates, T.; Dunst, R.; Forster, P. Seasonal Dry Matter, Starch, and Nutrient Distribution in 'Concord' Grapevine Roots. *HortScience* **2002**, *37*, 313–316. [CrossRef]
41. Field, S.K.; Smith, J.P.; Holzapfel, B.P.; Hardie, W.; Emery, R. Grapevine Response to Soil Temperature: Xylem Cytokinins and Carbohydrate Reserve Mobilization from Budbreak to Anthesis. *Am. J. Enol. Vitic.* **2009**, *60*, 164–172.
42. Spellman, G. Wine, Weather and Climate. *Weather* **1999**, *54*, 230–239. [CrossRef]
43. Gonzalez Antivilo, F.; Paz, R.C.; Tognetti, J.; Keller, M.; Cavagnaro, M.; Barrio, E.E.; Roig Juñent, F. Winter Injury to Grapevine Secondary Phloem and Cambium Impairs Budbreak, Cambium Activity, and Yield Formation. *J. Plant Growth Regul.* **2020**, *39*, 1095–1106. [CrossRef]
44. Winkler, A.J.; Cook, A.; Kliewer, W.M.; Lider, L.A. *General Viticulture*, 4th ed.; University of California Press: Berkeley, CA, USA, 1974; ISBN 978-0-520-01349-0.
45. Fennell, A. Freezing Tolerance and Injury in Grapevines. *J. Crop Improv.* **2004**, *10*, 201–235. [CrossRef]
46. Greer, D.H.; Weedon, M.M. Interactions between Light and Growing Season Temperatures on, Growth and Development and Gas Exchange of Semillon (*Vitis vinifera* L.) Vines Grown in an Irrigated Vineyard. *Plant Physiol. Biochem.* **2012**, *54*, 59–69. [CrossRef]
47. Bernardo, S.; Dinis, L.T.; Machado, N.; Moutinho-Pereira, J. Grapevine Abiotic Stress Assessment and Search for Sustainable Adaptation Strategies in Mediterranean-like Climates. A Review. *Agron. Sustain. Dev.* **2018**, *38*, 66. [CrossRef]
48. Tombesi, S.; Cincera, I.; Frioni, T.; Ughini, V.; Gatti, M.; Palliotti, A.; Poni, S. Relationship among Night Temperature, Carbohydrate Translocation and Inhibition of Grapevine Leaf Photosynthesis. *Environ. Exp. Bot.* **2019**, *157*, 293–298. [CrossRef]
49. De Orduña, R.M. Climate Change Associated Effects on Grape and Wine Quality and Production. *Food Res. Int.* **2010**, *43*, 1844–1855. [CrossRef]
50. Gouot, J.C.; Smith, J.P.; Holzapfel, B.P.; Barril, C. Impact of Short Temperature Exposure of *Vitis vinifera* L. Cv. Shiraz Grapevine Bunches on Berry Development, Primary Metabolism and Tannin Accumulation. *Environ. Exp. Bot.* **2019**, *168*, 103866. [CrossRef]
51. Zhang, L.; Li, X.; Pang, Y.; Cai, X.; Lu, J.; Ren, X.; Kong, Q. Phenolics Composition and Contents, as the Key Quality Parameters of Table Grapes, May Be Influenced Obviously and Differently in Response to Short-Term High Temperature. *LWT* **2021**, *149*, 111791. [CrossRef]
52. Berry, J.; Bjorkman, O. Photosynthetic Response and Adaptation to Temperature in Higher Plants. *Annu. Rev. Plant Physiol.* **2003**, *31*, 491–543. [CrossRef]
53. Venios, X.; Korkas, E.; Nisiotou, A.; Banilas, G. Grapevine Responses to Heat Stress and Global Warming. *Plants* **2020**, *9*, 1754. [CrossRef]

54. Steel, C.C.; Greer, D.H. Effect of Climate on Vine and Bunch Characteristics: Bunch Rot Disease Susceptibility. *Acta Hortic.* **2008**, *785*, 253–262. [CrossRef]
55. Poudel, P.R.; Mochioka, R.; Beppu, K.; Kataoka, I. Influence of Temperature on Berry Composition of Interspecific Hybrid Wine Grape 'Kadainou R-1' (Vitis Ficifolia Var. Ganebu × V. Vinifera 'Muscat of Alexandria'). *J. Jpn. Soc. Hort. Sci.* **2009**, *78*, 169–174. [CrossRef]
56. Petrie, P.R.; Sadras, V.O. Advancement of Grapevine Maturity in Australia between 1993 and 2006: Putative Causes, Magnitude of Trends and Viticultural Consequences. *Aust. J. Grape Wine Res.* **2008**, *14*, 33–45. [CrossRef]
57. Pastore, C.; Dal Santo, S.; Zenoni, S.; Movahed, N.; Allegro, G.; Valentini, G.; Filippetti, I.; Tornielli, G.B. Whole Plant Temperature Manipulation Affects Flavonoid Metabolism and the Transcriptome of Grapevine Berries. *Front. Plant Sci.* **2017**, *8*, 929. [CrossRef] [PubMed]
58. Arrizabalaga, M.; Morales, F.; Oyarzun, M.; Delrot, S.; Gomès, E.; Irigoyen, J.J.; Hilbert, G.; Pascual, I. Tempranillo Clones Differ in the Response of Berry Sugar and Anthocyanin Accumulation to Elevated Temperature. *Plant Sci.* **2018**, *267*, 74–83. [CrossRef] [PubMed]
59. Duchêne, E.; Huard, F.; Dumas, V.; Schneider, C.; Merdinoglu, D. The Challenge of Adapting Grapevine Varieties to Climate Change. *Clim. Res.* **2010**, *41*, 193–204. [CrossRef]
60. Ovadia, R.; Oren-Shamir, M.; Kaplunov, T.; Zutahy, Y.; Lichter, A.; Lurie, S. Effects of Plant Growth Regulators and High Temperature on Colour Development in 'Crimson Seedless' Grapes. *J. Hortic. Sci. Biotechnol.* **2013**, *88*, 387–392. [CrossRef]
61. Mori, K.; Goto-Yamamoto, N.; Kitayama, M.; Hashizume, K. Loss of Anthocyanins in Red-Wine Grape under High Temperature. *J. Exp. Bot.* **2007**, *58*, 1935–1945. [CrossRef]
62. González-Barreiro, C.; Rial-Otero, R.; Cancho-Grande, B.; Simal-Gándara, J. Wine Aroma Compounds in Grapes: A Critical Review. *Crit. Rev. Food Sci. Nutr.* **2015**, *55*, 202–218. [CrossRef]
63. Asproudi, A.; Petrozziello, M.; Cavalletto, S.; Guidoni, S. Grape Aroma Precursors in Cv. Nebbiolo as Affected by Vine Microclimate. *Food Chem.* **2016**, *211*, 947–956. [CrossRef]
64. Costa, C.; Graça, A.; Fontes, N.; Teixeira, M.; Gerós, H.; Santos, J.A. The Interplay between Atmospheric Conditions and Grape Berry Quality Parameters in Portugal. *Appl. Sci.* **2020**, *10*, 4943. [CrossRef]
65. Ramos, M.C.; Martínez de Toda, F. Variability of Tempranillo Grape Composition in the Rioja DOCa (Spain) Related to Soil and Climatic Characteristics. *J. Sci. Food Agric.* **2019**, *99*, 1153–1165. [CrossRef]
66. Barnuud, N.N.; Zerihun, A.; Gibberd, M.; Bates, B. Berry Composition and Climate: Responses and Empirical Models. *Int. J. Biometeorol.* **2014**, *58*, 1207–1223. [CrossRef]
67. Pedneault, K.; Dorais, M.; Angers, P. Flavor of Cold-Hardy Grapes: Impact of Berry Maturity and Environmental Conditions. *J. Agric. Food Chem.* **2013**, *61*, 10418–10438. [CrossRef] [PubMed]
68. Ubalde, J.M.; Sort, X.; Zayas, A.; Poch, R.M. Effects of Soil and Climatic Conditions on Grape Ripening and Wine Quality of Cabernet Sauvignon. *J. Wine Res.* **2010**, *21*, 1–17. [CrossRef]
69. Meier, N.; Rutishauser, T.; Pfister, C.; Wanner, H.; Luterbacher, J. Grape Harvest Dates as a Proxy for Swiss April to August Temperature Reconstructions Back to AD 1480. *Geophys. Res. Lett.* **2007**, *34*, L20705. [CrossRef]
70. Jones, G.V.; Davis, R.E. Climate Influences on Grapevine Phenology, Grape Composition, and Wine Production and Quality for Bordeaux, France. *Am. J. Enol. Vitic.* **2000**, *51*, 249–261.
71. Duchêne, E.; Schneider, C. Grapevine and Climatic Changes: A Glance at the Situation in Alsace. *Agron. Sustain. Dev.* **2005**, *25*, 93–99. [CrossRef]
72. Ferretti, C. Topoclimate and Wine Quality: Results of Research on the Gewürztraminer Grape Variety in South Tyrol, Northern Italy. *OENO One* **2021**, *55*, 313–335. [CrossRef]
73. Ramos, M.C.; Jones, G.V.; Martínez-Casasnovas, J.A. Structure and Trends in Climate Parameters Affecting Winegrape Production in Northeast Spain. *Clim. Res.* **2008**, *38*, 1–15. [CrossRef]
74. Camps, J.O.; Ramos, M.C. Grape Harvest and Yield Responses to Inter-Annual Changes in Temperature and Precipitation in an Area of North-East Spain with a Mediterranean Climate. *Int. J. Biometeorol.* **2012**, *56*, 853–864. [CrossRef]
75. van Leeuwen, C.; Darriet, P. The Impact of Climate Change on Viticulture and Wine Quality. *J. Wine Econ.* **2016**, *11*, 150–167. [CrossRef]
76. Drappier, J.; Thibon, C.; Rabot, A.; Geny-Denis, L. Relationship between Wine Composition and Temperature: Impact on Bordeaux Wine Typicity in the Context of Global Warming—Review. *Crit. Rev. Food Sci. Nutr.* **2019**, *59*, 14–30. [CrossRef]
77. Schultz, H.R.; Lebon, E. Modelling the Effect of Climate Change on Grapevine Water Relations. *Acta Hortic.* **2005**, *689*, 71–78. [CrossRef]
78. Ramos, M.C.; Martínez-Casasnovas, J.A. Soil Water Balance in Rainfed Vineyards of the Penedès Region (Northeastern Spain) Affected by Rainfall Characteristics and Land Levelling: Influence on Grape Yield. *Plant Soil* **2010**, *333*, 375–389. [CrossRef]
79. Fraga, H.; Malheiro, A.C.; Moutinho-Pereira, J.; Cardoso, R.M.; Soares, P.M.M.; Cancela, J.J.; Pinto, J.G.; Santos, J.A. Integrated Analysis of Climate, Soil, Topography and Vegetative Growth in Iberian Viticultural Regions. *PLoS ONE* **2014**, *9*, e108078. [CrossRef] [PubMed]
80. Sadras, V.; Moran, M.; Petrie, P. Resilience of Grapevine Yield in Response to Warming. *OENO One* **2017**, *51*, 381–386. [CrossRef]
81. Santos, J.A.; Grätsch, S.D.; Karremann, M.K.; Jones, G.V.; Pinto, J.G. Ensemble Projections for Wine Production in the Douro Valley of Portugal. *Clim. Chang.* **2013**, *117*, 211–225. [CrossRef]

82. Fraga, H.; Malheiro, A.C.; Moutinho-Pereira, J.; Santos, J.A. Climate Factors Driving Wine Production in the Portuguese Minho Region. *Agric. For. Meteorol.* **2014**, *185*, 26–36. [CrossRef]
83. White, M.A.; Diffenbaugh, N.S.; Jones, G.V.; Pal, J.S.; Giorgi, F. Extreme Heat Reduces and Shifts United States Premium Wine Production in the 21st Century. *Proc. Natl. Acad. Sci. USA* **2006**, *103*, 11217–11222. [CrossRef]
84. Huang, X.; Shi, Z.H.; Zhu, H.D.; Zhang, H.Y.; Ai, L.; Yin, W. Soil Moisture Dynamics within Soil Profiles and Associated Environmental Controls. *Catena* **2016**, *136*, 189–196. [CrossRef]
85. Schoener, G.; Stone, M.C. Monitoring Soil Moisture at the Catchment Scale—A Novel Approach Combining Antecedent Precipitation Index and Radar-Derived Rainfall Data. *J. Hydrol.* **2020**, *589*, 125–155. [CrossRef]
86. Rodrigues, P.; Pedroso, V.; Gouveia, J.P.; Martins, S.; Lopes, C.; Alves, I. Influence of Soil Water Content and Atmospheric Conditions on Leaf Water Potential in Cv. "Touriga Nacional" Deep-Rooted Vineyards. *Irrig. Sci.* **2012**, *30*, 407–417. [CrossRef]
87. Gaudin, R.; Roux, S.; Tisseyre, B. Linking the Transpirable Soil Water Content of a Vineyard to Predawn Leaf Water Potential Measurements. *Agric. Water Manag.* **2017**, *182*, 13–23. [CrossRef]
88. Suter, B.; Triolo, R.; Pernet, D.; Dai, Z.; Van Leeuwen, C. Modeling Stem Water Potential by Separating the Effects of Soil Water Availability and Climatic Conditions on Water Status in Grapevine (*Vitis vinifera* L.). *Front. Plant Sci.* **2019**, *10*, 1485. [CrossRef] [PubMed]
89. Nemani, R.R.; White, M.A.; Cayan, D.R.; Jones, G.V.; Running, S.W.; Coughlan, J.C.; Peterson, D.L. Asymmetric Warming over Coastal California and Its Impact on the Premium Wine Industry. *Clim. Res.* **2001**, *19*, 25–34. [CrossRef]
90. Wheeler, S.J.; Pickering, G.J. The Effects of Soil Management Techniques on Grape and Wine Quality. In *Fruits: Growth, Nutrition and Quality*; Dris, R., Ed.; WFL Publisher, Meri-Rastilan tie 3 C: Helsinki, Finland, 2006; pp. 195–208. ISBN 978-952-99555-0-3.
91. Kassemeyer, H.-H. Fungi of Grapes. In *Biology of Microorganisms on Grapes, in Must and in Wine*; König, H., Unden, G., Fröhlich, J., Eds.; Springer International Publishing: Cham, Switzerland, 2017; pp. 103–132. ISBN 978-3-319-60021-5.
92. Austin, C.N.; Wilcox, W.F. Effects of Sunlight Exposure on Grapevine Powdery Mildew Development. *Phytopathology* **2012**, *102*, 857–866. [CrossRef] [PubMed]
93. Valdés-Gómez, H.; Fermaud, M.; Roudet, J.; Calonnec, A.; Gary, C. Grey Mould Incidence Is Reduced on Grapevines with Lower Vegetative and Reproductive Growth. *Crop Prot.* **2008**, *27*, 1174–1186. [CrossRef]
94. Agosta, E.; Canziani, P.; Cavagnaro, M. Regional Climate Variability Impacts on the Annual Grape Yield in Mendoza, Argentina. *J. Appl. Meteorol. Climatol.* **2012**, *51*, 993–1009. [CrossRef]
95. Reynolds, A.G.; Naylor, A.P. 'Pinot Noir' and 'Riesling' Grapevines Respond to Water Stress Duration and Soil Water-Holding Capacity. *HortScience* **1994**, *29*, 1505–1510. [CrossRef]
96. Storchi, P.; Costantini, E.A.C.; Bucelli, P. The Influence of Climate and Soil on Viticultural and Enological Parameters of ´Sangiovese´ Grapevines under Non-Irrigated Conditions. *Acta Hortic.* **2005**, *689*, 333–340. [CrossRef]
97. Bondada, B.; Shutthanandan, J. Understanding Differential Responses of Grapevine (*Vitis vinifera* L.) Leaf and Fruit to Water Stress and Recovery Following Re-Watering. *Am. J. Plant Sci.* **2012**, *3*, 1232–1240. [CrossRef]
98. dos Santos, T.P.; Lopes, C.M.; Rodrigues, M.L.; de Souza, C.R.; Maroco, J.P.; Pereira, J.S.; Silva, J.R.; Chaves, M.M. Partial Rootzone Drying: Effects on Growth and Fruit Quality of Field-Grown Grapevines (*Vitis vinifera*). *Funct. Plant Biol.* **2003**, *30*, 663–671. [CrossRef]
99. Cifre, J.; Bota, J.; Escalona, J.M.; Medrano, H.; Flexas, J. Physiological Tools for Irrigation Scheduling in Grapevine (*Vitis vinifera* L.): An Open Gate to Improve Water-Use Efficiency? *Agric. Ecosyst. Environ.* **2005**, *106*, 159–170. [CrossRef]
100. Alatzas, A.; Theocharis, S.; Miliordos, D.-E.; Leontaridou, K.; Kanellis, A.K.; Kotseridis, Y.; Hatzopoulos, P.; Koundouras, S. The Effect of Water Deficit on Two Greek *Vitis vinifera* L. Cultivars: Physiology, Grape Composition and Gene Expression during Berry Development. *Plants* **2021**, *10*, 1947. [CrossRef] [PubMed]
101. Chacón-Vozmediano, J.L.; Martínez-Gascueña, J.; García-Navarro, F.J.; Jiménez-Ballesta, R. Effects of Water Stress on Vegetative Growth and 'Merlot' Grapevine Yield in a Semi-Arid Mediterranean Climate. *Horticulturae* **2020**, *6*, 95. [CrossRef]
102. Cabral, I.L.; Teixeira, A.; Lanoue, A.; Unlubayir, M.; Munsch, T.; Valente, J.; Alves, F.; da Costa, P.L.; Rogerson, F.S.; Carvalho, S.M.P.; et al. Impact of Deficit Irrigation on Grapevine Cv. 'Touriga Nacional' during Three Seasons in Douro Region: An Agronomical and Metabolomics Approach. *Plants* **2022**, *11*, 732. [CrossRef] [PubMed]
103. Gambetta, G.A.; Herrera, J.C.; Dayer, S.; Feng, Q.; Hochberg, U.; Castellarin, S.D. The Physiology of Drought Stress in Grapevine: Towards an Integrative Definition of Drought Tolerance. *J. Exp. Bot.* **2020**, *71*, 4658–4676. [CrossRef] [PubMed]
104. Chaves, M.M.; Zarrouk, O.; Francisco, R.; Costa, J.M.; Santos, T.; Regalado, A.P.; Rodrigues, M.L.; Lopes, C.M. Grapevine under Deficit Irrigation: Hints from Physiological and Molecular Data. *Ann. Bot.* **2010**, *105*, 661–676. [CrossRef]
105. Flexas, J.; Bota, J.; Escalona, J.M.; Sampol, B.; Medrano, H. Effects of Drought on Photosynthesis in Grapevines under Field Conditions: An Evaluation of Stomatal and Mesophyll Limitations. *Funct. Plant Biol.* **2002**, *29*, 461–471. [CrossRef]
106. Maroco, J.P.; Rodrigues, M.L.; Lopes, C.; Chaves, M.M. Limitations to Leaf Photosynthesis in Field-Grown Grapevine under Drought—Metabolic and Modelling Approaches. *Funct. Plant Biol.* **2002**, *29*, 451–459. [CrossRef]
107. Kizildeniz, T.; Irigoyen, J.J.; Pascual, I.; Morales, F. Simulating the Impact of Climate Change (Elevated CO2 and Temperature, and Water Deficit) on the Growth of Red and White Tempranillo Grapevine in Three Consecutive Growing Seasons (2013–2015). *Agric. Water Manag.* **2018**, *202*, 220–230. [CrossRef]
108. Gambetta, G.A. Water Stress and Grape Physiology in the Context of Global Climate Change. *J. Wine Econ.* **2016**, *11*, 168–180. [CrossRef]

109. Zhang, Q.; Chen, Y.; Xiong, Y.J.; Shigeoki, M.; Wu, X.; Yan, C.; Chen, X. Which Is More Sensitive to Water Stress for Irrigation Scheduling during the Maturation Stage: Grapevine Photosynthesis or Berry Size? *Atmosphere* **2021**, *12*, 845. [CrossRef]
110. Beauchet, S.; Cariou, V.; Renaud-Gentié, C.; Meunier, M.; Siret, R.; Thiollet-Scholtus, M.; Jourjon, F. Modeling Grape Quality by Multivariate Analysis of Viticulture Practices, Soil and Climate. *OENO One* **2020**, *54*, 601–622. [CrossRef]
111. Deluc, L.G.; Quilici, D.R.; Decendit, A.; Grimplet, J.; Wheatley, M.D.; Schlauch, K.A.; Mérillon, J.-M.; Cushman, J.C.; Cramer, G.R. Water Deficit Alters Differentially Metabolic Pathways Affecting Important Flavor and Quality Traits in Grape Berries of Cabernet Sauvignon and Chardonnay. *BMC Genom.* **2009**, *10*, 212. [CrossRef] [PubMed]
112. Matthews, M.A.; Anderson, M.M. Fruit Ripening in *Vitis vinifera* L.: Responses to Seasonal Water Deficits. *Am. J. Enol. Vitic.* **1988**, *39*, 313–320.
113. Ojeda, H.; Andary, C.; Kraeva, E.; Carbonneau, A.; Deloire, A. Influence of Pre- and Postveraison Water Deficit on Synthesis and Concentration of Skin Phenolic Compounds during Berry Growth of *Vitis vinifera* Cv. Shiraz. *Am. J. Enol. Vitic.* **2002**, *53*, 261–267.
114. Roby, G.; Harbertson, J.F.; Adams, D.A.; Matthews, M.A. Berry Size and Vine Water Deficits as Factors in Winegrape Composition: Anthocyanins and Tannins. *Aust. J. Grape Wine Res.* **2004**, *10*, 100–107. [CrossRef]
115. Castellarin, S.D.; Matthews, M.A.; Di Gaspero, G.; Gambetta, G.A. Water Deficits Accelerate Ripening and Induce Changes in Gene Expression Regulating Flavonoid Biosynthesis in Grape Berries. *Planta* **2007**, *227*, 101–112. [CrossRef]
116. Castellarin, S.D.; Pfeiffer, A.; Sivilotti, P.; Degan, M.; Peterlunger, E.; Di Gaspero, G. Transcriptional Regulation of Anthocyanin Biosynthesis in Ripening Fruits of Grapevine under Seasonal Water Deficit. *Plant Cell Environ.* **2007**, *30*, 1381–1399. [CrossRef]
117. Huglin, P. A new method of evaluating the heliothermal possibilities in the environment of grape culture. *C. R. Acad. Agric. Fr.* **1978**, *64*, 1117–1126.
118. Tonietto, J.; Carbonneau, A. A Multicriteria Climatic Classification System for Grape-Growing Regions Worldwide. *Agric. For. Meteorol.* **2004**, *124*, 81–97. [CrossRef]
119. Jones, G. Climate Change and Wine: Observations, Impacts and Future Implications. *WIJ* **2006**, *21*, 21–26.
120. Kenny, G.J.; Harrison, P.A. The Effects of Climate Variability and Change on Grape Suitability in Europe. *J. Wine Res.* **1992**, *3*, 163–183. [CrossRef]
121. Fraga, H.; Malheiro, A.C.; Moutinho-Pereira, J.; Santos, J.A. Future Scenarios for Viticultural Zoning in Europe: Ensemble Projections and Uncertainties. *Int. J. Biometeorol.* **2013**, *57*, 909–925. [CrossRef] [PubMed]
122. Malheiro, A.C.; Santos, J.A.; Fraga, H.; Pinto, J.G. Climate Change Scenarios Applied to Viticultural Zoning in Europe. *Clim. Res.* **2010**, *43*, 163–177. [CrossRef]
123. Moriondo, M.; Jones, G.V.; Bois, B.; Dibari, C.; Ferrise, R.; Trombi, G.; Bindi, M. Projected Shifts of Wine Regions in Response to Climate Change. *Clim. Chang.* **2013**, *119*, 825–839. [CrossRef]
124. Charalampopoulos, I.; Polychroni, I.; Psomiadis, E.; Nastos, P. Spatiotemporal Estimation of the Olive and Vine Cultivations' Growing Degree Days in the Balkans Region. *Atmosphere* **2021**, *12*, 148. [CrossRef]
125. Charalampopoulos, I. Agrometeorological Conditions and Agroclimatic Trends for the Maize and Wheat Crops in the Balkan Region. *Atmosphere* **2021**, *12*, 671. [CrossRef]
126. Teslić, N.; Zinzani, G.; Parpinello, G.P.; Versari, A. Climate Change Trends, Grape Production, and Potential Alcohol Concentration in Wine from the "Romagna Sangiovese" Appellation Area (Italy). *Theor. Appl. Climatol.* **2018**, *131*, 793–803. [CrossRef]
127. Bock, A.; Sparks, T.; Estrella, N.; Menzel, A. Changes in the Phenology and Composition of Wine from Franconia, Germany. *Clim. Res.* **2011**, *50*, 69–81. [CrossRef]
128. Webb, L.B.; Whetton, P.H.; Barlow, E.W.R. Observed Trends in Winegrape Maturity in Australia. *Glob. Chang. Biol.* **2011**, *17*, 2707–2719. [CrossRef]
129. van Eck, N.; Waltman, L. Software Survey: VOSviewer, a Computer Program for Bibliometric Mapping. *Scientometrics* **2009**, *84*, 523–538. [CrossRef] [PubMed]
130. Laget, F.; Tondut, J.-L.; Deloire, A.; Kelly, M.T. Climate Trends in a Specific Mediterranean Viticultural Area between 1950 and 2006. *J. Int. Sci. Vigne Vin.* **2008**, *42*, 113–123. [CrossRef]
131. Neethling, E.; Barbeau, G.; Bonnefoy, C.; Quénol, H. Change in Climate and Berry Composition for Grapevine Varieties Cultivated in the Loire Valley. *Clim. Res.* **2012**, *53*, 89–101. [CrossRef]
132. Cook, B.I.; Wolkovich, E.M. Climate Change Decouples Drought from Early Wine Grape Harvests in France. *Nat. Clim. Chang.* **2016**, *6*, 715–719. [CrossRef]
133. Di Lena, B.; Silvestroni, O.; Lanari, V.; Palliotti, A. Climate Change Effects on Cv. Montepulciano in Some Wine-Growing Areas of the Abruzzi Region (Italy). *Theor. Appl. Climatol.* **2019**, *136*, 1145–1155. [CrossRef]
134. Di Lena, B.; Silvestroni, O.; Mariani, L.; Parisi, S.; Antenucci, F. European Climate Variability Effects on Grapevine Harvest Date Time Series in the Abruzzi (Italy). *Acta Hortic.* **2012**, *931*, 63–69. [CrossRef]
135. Di Carlo, P.; Aruffo, E.; Brune, W.H. Precipitation Intensity under a Warming Climate Is Threatening Some Italian Premium Wines. *Sci. Total Environ.* **2019**, *685*, 508–513. [CrossRef]
136. Biasi, R.; Brunori, E.; Ferrara, C.; Salvati, L. Assessing Impacts of Climate Change on Phenology and Quality Traits of *Vitis vinifera* L.: The Contribution of Local Knowledge. *Plants* **2019**, *8*, 121. [CrossRef]
137. Urhausen, S.; Brienen, S.; Kapala, A.; Simmer, C. Climatic Conditions and Their Impact on Viticulture in the Upper Moselle Region. *Clim. Chang.* **2011**, *109*, 349–373. [CrossRef]
138. Koch, B.; Oehl, F. Climate Change Favors Grapevine Production in Temperate Zones. *Agric. Sci.* **2018**, *9*, 247–263. [CrossRef]

139. Karvonen, J. Changes in the Grapevine's Growth Cycle in Southern Finland in the 2000s—Comparison between Two First Decades. *Clim. Chang.* **2020**, *6*, 94–99.
140. Baduca Campeanu, C.; Beleniuc, G.; Simionescu, V.; Panaitescu, L.; Grigorica, L. Climate Change Effects on Ripening Process and Wine Composition in Oltenia's Vineyards from Romania. *Acta Hortic.* **2012**, *931*, 47–54. [CrossRef]
141. Lisek, J. Climatic Factors Affecting Development and Yielding of Grapevine in Central Poland. *J. Fruit Ornam. Plant Res.* **2008**, *16*, 285–293.
142. Kovács, E.; Puskás, J.; Pozsgal, A.; Kozma, K. Shift in the Annual Growth Cycle of Grapevines (*Vitis vinifera* L.) in West Hungary. *Appl. Ecol. Env. Res.* **2018**, *16*, 2029–2042. [CrossRef]
143. Ruml, M.; Korać, N.; Vujadinović, M.; Vuković, A.; Ivanišević, D. Response of Grapevine Phenology to Recent Temperature Change and Variability in the Wine-Producing Area of Sremski Karlovci, Serbia. *J. Agric. Sci.* **2016**, *154*, 186–206. [CrossRef]
144. Ivanišević, D.; Kalajdžić, M.; Alesandar, T.; Jakšić, D. Phenological Stages of Some Grapevine Cultivars in North Serbia: Historical Data and Current State. *BIO Web Conf.* **2019**, *15*, 01023. [CrossRef]
145. Vršič, S.; Vodovnik, T. Reactions of Grape Varieties to Climate Changes in North East Slovenia. *Plant Soil Environ.* **2012**, *58*, 34–41. [CrossRef]
146. Vršič, S.; Šuštar, V.; Pulko, B.; Šumenjak, T.K. Trends in Climate Parameters Affecting Winegrape Ripening in Northeastern Slovenia. *Clim. Res.* **2014**, *58*, 257–266. [CrossRef]
147. Bernáth, S.; Paulen, O.; Šiška, B.; Kusá, Z.; Tóth, F. Influence of Climate Warming on Grapevine (*Vitis vinifera* L.) Phenology in Conditions of Central Europe (Slovakia). *Plants* **2021**, *10*, 1020. [CrossRef]
148. Koufos, G.; Mavromatis, T.; Koundouras, S.; Fyllas, N.M.; Jones, G.V. Viticulture–Climate Relationships in Greece: The Impacts of Recent Climate Trends on Harvest Date Variation. *Int. J. Climatol.* **2014**, *34*, 1445–1459. [CrossRef]
149. Koufos, G.C.; Mavromatis, T.; Koundouras, S.; Jones, G.V. Adaptive Capacity of Winegrape Varieties Cultivated in Greece to Climate Change: Current Trends and Future Projections. *OENO One* **2020**, *54*, 1201–1219. [CrossRef]
150. Lereboullet, A.-L.; Beltrando, G.; Bardsley, D.K.; Rouvellac, E. The Viticultural System and Climate Change: Coping with Long-Term Trends in Temperature and Rainfall in Roussillon, France. *Reg. Environ. Chang.* **2014**, *14*, 1951–1966. [CrossRef]
151. Schultz, H.R.; Jones, G.V. Climate Induced Historic and Future Changes in Viticulture. *J. Wine Res.* **2010**, *21*, 137–145. [CrossRef]
152. Bock, A.; Sparks, T.H.; Estrella, N.; Menzel, A. Climate-Induced Changes in Grapevine Yield and Must Sugar Content in Franconia (Germany) between 1805 and 2010. *PLoS ONE* **2013**, *8*, e69015. [CrossRef] [PubMed]
153. Gentilucci, M.; Materazzi, M.; Pambianchi, G.; Burt, P.; Guerriero, G. Temperature Variations in Central Italy (Marche Region) and Effects on Wine Grape Production. *Theor. Appl. Climatol.* **2020**, *140*, 303–312. [CrossRef]
154. Nesbitt, A.; Dorling, S.; Jones, R. Climate Resilience in the United Kingdom Wine Production Sector: CREWS-UK. *BIO Web Conf.* **2019**, *15*, 01011. [CrossRef]
155. Nesbitt, A.; Kemp, B.; Steele, C.; Lovett, A.; Dorling, S. Impact of Recent Climate Change and Weather Variability on the Viability of UK Viticulture—Combining Weather and Climate Records with Producers' Perspectives. *Aust. J. Grape Wine Res.* **2016**, *22*, 324–335. [CrossRef]
156. Smith, V.; Bentzen, J. Which Factors Influence the Quality of Wine Produced in New Cool Climate Regions? *IJWBR* **2011**, *23*, 355–373. [CrossRef]
157. Karvonen, J. Does Climate Change Allow Grapevine Growing in the Southernmost Finland. *Int. J. Agric. Innov. Res.* **2015**, *4*, 201–204.
158. Maciejczak, M.; Mikiciuk, J. Climate Change Impact on Viticulture in Poland. *Int. J. Clim. Chang. Strateg.* **2019**, *11*, 254–264. [CrossRef]
159. Mazurkiewicz-Pizło, A.; Pizło, W. Determinants of the Development of Vineyards and Wine Tourism in Poland. *Acta Sci. Pol. Oecon.* **2018**, *17*, 115–121. [CrossRef]
160. Pijet-Migoń, E.; Królikowska, K. Rebirth of Viticulture and Associated Changes in the Rural Areas of Lower Silesia, SW Poland. *Geogr. Pol.* **2020**, *93*, 321–340. [CrossRef]
161. Kovács, E.; Puskas, J.; Pozsgai, A. Positive Effects of Climate Change on the Field of Sopron Wine-Growing Region in Hungary. In *Perspectives on Atmospheric Sciences*; Karacostas, T., Bais, A., Nastos, P.T., Eds.; Springer Atmospheric Sciences; Springer International Publishing: Cham, Switzerland, 2017; pp. 607–613. ISBN 978-3-319-35095-0.
162. Monteith, J.L. Agricultural Meteorology: Evolution and Application. *Agric. For. Meteorol.* **2000**, *103*, 5–9. [CrossRef]
163. Field, C.B.; Barros, V.; Stocker, T.F.; Qin, D.; Dokken, D.J.; Ebi, K.L.; Mastandrea, M.D.; Mach, K.; Plattner, G.-K.; Allen, S.K.; et al. (Eds.) IPCC, 2012: Glossary of Terms. In *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation: Special Report of the Intergovernmental Panel on Climate Change*; Cambridge University Press: Cambridge, UK, 2012; pp. 555–564.
164. Robinson, J. *The Oxford Companion to Wine*, 4th ed.; Robinson, J., Harding, J., Eds.; Oxford University Press: Oxford, UK, 2015; ISBN 978-0-19-870538-3.
165. Lereboullet, A.-L.; Beltrando, G.; Bardsley, D.K. Socio-Ecological Adaptation to Climate Change: A Comparative Case Study from the Mediterranean Wine Industry in France and Australia. *Agric. Ecosyst. Environ.* **2013**, *164*, 273–285. [CrossRef]
166. van Leeuwen, C.; Destrac-Irvine, A.; de Resseguier, L.; Garcia de Cortazar-Atauri, I.; Duchêne, É.; Barbeau, G.; Dufourcq, T. Phenology: Follow the Internal Clock of the Vines. Available online: https://ives-technicalreviews.eu/article/view/2587 (accessed on 26 November 2021).

167. Keller, M. Managing Grapevines to Optimise Fruit Development in a Challenging Environment: A Climate Change Primer for Viticulturists. *Aust. J. Grape Wine Res.* **2010**, *16*, 56–69. [CrossRef]
168. USA National Phenology Network. Phenophase. Available online: https://usanpn.org/taxonomy/term/16 (accessed on 6 January 2022).
169. Lorenz, D.H.; Eichhorn, K.W.; Bleiholder, H.; Klose, R.; Meier, U.; Weber, E. Growth Stages of the Grapevine: Phenological Growth Stages of the Grapevine (*Vitis vinifera* L. ssp. Vinifera)—Codes and Descriptions According to the Extended BBCH Scale. *Aust. J. Grape Wine Res.* **1995**, *1*, 100–103. [CrossRef]
170. Fernández-González, M.; Escuredo, O.; Rodriguez Rajo, F.J.; Aira, M.; Jato, V. Prediction of Grape Production by Grapevine Cultivar Godello in North-West Spain. *J. Agric. Sci.* **2011**, *149*, 725–736. [CrossRef]
171. McIntyre, G.N.; Lider, L.A.; Ferrari, N.L. The Chronological Classification of Grapevine Phenology. *Am. J. Enol. Vitic.* **1982**, *33*, 80–85.
172. Santos, J.A.; Fraga, H.; Malheiro, A.C.; Moutinho-Pereira, J.; Dinis, L.-T.; Correia, C.; Moriondo, M.; Leolini, L.; Dibari, C.; Costafreda-Aumedes, S.; et al. A Review of the Potential Climate Change Impacts and Adaptation Options for European Viticulture. *Appl. Sci.* **2020**, *10*, 3092. [CrossRef]
173. Souza Gonzaga, L.; Capone, D.L.; Bastian, S.E.P.; Jeffery, D.W. Defining Wine Typicity: Sensory Characterisation and Consumer Perspectives. *Aust. J. Grape Wine Res.* **2021**, *27*, 246–256. [CrossRef]