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Climate Change and the Wine Quality in Bordeaux Region

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ABSTRACT

Climate change: Can Bordeaux remain at the wine industry forefront? To answer this question, this study aims to investigate the impact of the Climate Change in the Bordeaux wine typicity, quality and market/economy through the bioclimatic índices and grapevine physiology data, such as grape sugar content, total acidity, and weight, in order to gauge the possible correlations between them over a period of forty-five years. A statistical method, regression analysis, has been used to investigate this correlations between the variables. Meteoblue AG has provided historic weather data for the three sites in the Bordeaux region: Listrac Medoc, Saint Emilion and Pessac. The biochemistry data were provided by *The Institut des Sciences de la Vigne et du Vin de l'Université de Bordeaux* for the 1977-2022 period.

There is a strong scientific consensus regarding the effects of climate change when it comes to the winegrape production, the wine quality and wine economics within the various wine regions worldwide, unsurprisingly within Bordeaux, as well. These impacts can be either positive or negative, depending on several factors, for instance, local specificities, agronomic practices and grape varieties. The wine industry has motivated a multidisciplinary and transverse approach that involves concerns which have not been yet tackled and which have only been snowballing, such as the sustainability and wine economics in the fields of vineyard, production, environment, distribution and consumption.

Results and conclusions obtained by this study show that they are consistent and in line with previous researches into the effects of climate change on the quality and economics of Bordeaux wine. Moreover, the study shows, through bioclimatic indices, that the Bordeaux region had reached an optimal level for the production of premium wines in the late 1980s, which has been maintened and it will probably continue at this level for quite some time. It has allowed the Bordeaux wine industry to retain and to continue having a privileged position among wine lovers and wine dealers throughout the world.

Keywords: Climate change, Bordeaux, quality, bioclimatic indices, sugar content, acidity.

Acknowledgments

I would like to thank Meteoblue AG that kindly provided the historical weather data. I would like to thank all the professores and administration staff of the MSc. Wine & Spirits Management course for the outstanding technical excellence. I would also like to thank my classmates for all the memorable moments we have spent together during this journey, which will be deeply cherished. Last but not least, a big thank you goes to my advisor, Florine Livat-Pécheux, not only for her accepting to conduct this study, but also her trust, guidance and constructive ideas, which have been instrumental throughout the process.

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1. Introduction

Climate and weather have been determining factors closely linked to agricultural productivity. The important role of climate and weather in the agriculture activities and human existence is not recent (Jones & Webb, 2010). Nomadic tribes moved during thousands of years looking for the best climatic conditions for the crops and also to feed their animals. As in the past, climate and weather continue to play a critical role in agricultural systems. In addition, recently, new components have become part of this scenario: sustainability and abrupt Climate Change, imposing challenges and opportunities.

There is a strong scientific consensus regarding Climate Change (CC) which refers to long-term shifts in temperatures and weather patterns. According to Intergovernmental Panel on Climate Change, the atmosphere and the oceans have warmed since the 1950s and such observed changes have reached an unprecedented level, Figure 1. The temperature of the Earth’s surface has successively increased during the last three decades, findings show from the study concluded in 2014. Moreover, the period between 1983 and 2012 was the warmest 30-year interval in the last 1,400 years in the Northern hemisphere (IPCC, 2014).

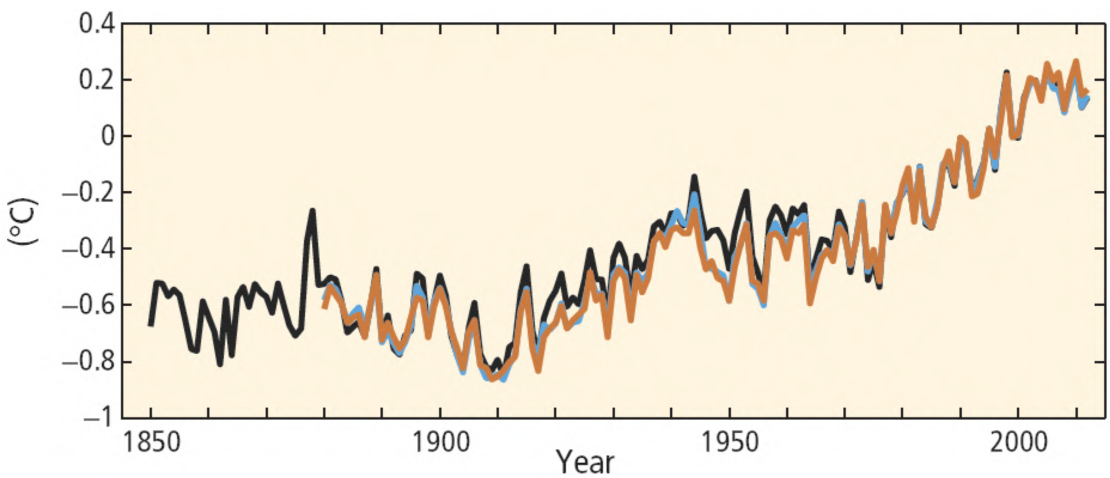

Figure 1. Globally averaged combined land and ocean surface temperature anomaly
Source: IPCC (2014)

However, the global warming is not the only problem caused by those shifts. Extreme event changes have also been observed. Even though some of these shifts may be natural, since 1950s, human activities have been the main driver of the climate change. Among those events the temperature extremes, both low and high, the rise of global sea levels, long-term droughts and increased heavy precipitations in many regions, have been the most notorious ones. According to the scenarios outlined by the IPCC, the continued emission of greenhouse gases should maintain the warming-up trend, Figure 2, exerting influence on various components of the climate system, causing an ever-increasing impact on the environment and population, augmenting harsher present and future climate conditions.

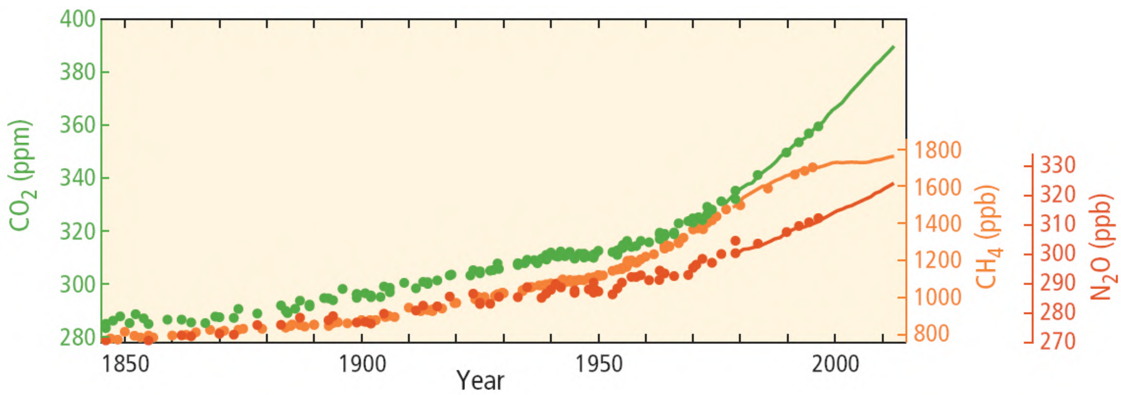

Figure 2. Globally averaged greenhouse gas concentration
Source: IPCC (2014)

Aforementioned issues have caused a blow to the global winegrapes and wine production. Climate Change can have both positive and negative impacts on the global wine industries. Several studies (Jobien-Poirier et al., 2020; Battaglini, Barbeau, Bindi & Badeck, 2009; Navrátilová et al., 2020; Ollat, Van Leeuwen, Cortazar-Atauri & Touzard, 2017; Mozell & Thach, 2014; Jones et al., 2000; Tonietto & Carbonneau, 2004; Lecocq & Visser, 2006) conducted in various wine regions on different continents, have concluded that Climate Change has indeed impacted the winegrape production and the wine quality itself.

Therefore, there is no longer any shred of doubt around the effects of climate change in the production of winegrapes, the wine quality and economics in various wine regions throughout the world. Studies and researches should focus on how climate changes impact each region differently, be it positive or negative, and how to take the advantage of the positive changes, or how to mitigate and/or adapt, if those changes are negative.

Since Bordeaux is the world-renowned centre of viniculture in the world, it is quite expected that many researchers, scientists and institutions, linked to the segment, are interested in numerous topics related to the wine industry in the region. As a consequence, it has resulted in a multidisciplinary approach, involving several branches of science: new technologies, agronomic practices, plant material, production process, sustainability, and wine economics, but to mention a few.

Renowned scientists such as Gregory Jones of the Southern Oregon University, Orley Ashenfelter, Princeton economics professor and the editor of the American Economic Review, Sébastien Lecocoq and Gilles de Revel from Université de Bordeaux have carried out several studies aimed at the Bordeaux region.

Research and Development institutions and organizations, such as The Institute of Vine and Wine Sciences (ISVV), *The Institut des Sciences de la Vigne et du Vin de l'Université de Bordeaux*, and *Conseil Interprofessionnel du Vin de Bordeaux* (CIVB) have also produced a lot of useful information and recommendations for the local wine industry.

The main concern of the stakeholders of the Bordeaux wine industry is the impact that climate change could have on the wine quality in the region, which, for centuries, has been known for its finesse, balance and elegance. Negative impacts, without mitigation and adaptation, could change those characteristics which made it a unique product and consequently, could have the existing market share affected not only by demand, but also by price.

Based on the conclusions and suggestions provided in the studies and surveys, we will aim to investigate the impact of the Climate Change on the Bordeaux wine typicity, economic, and quality through the bioclimatic indices (Huglin, Growing season temperature average, and Prior to harvest cool night index), grape sugar content, total acidity, and berry weight in order to gauge possible correlations between them for over a period of 40 years. The gathered data and information will be subjected to quantitative research, regression analysys, for further evaluation, analyses and conclusions.

Table 1. Workflow of the project

Data	Indices	Quantitative Research	Evaluation & Conclusions
• Temperatures • Sugar level • Total acidity, • Berry weight	• Huglin Index (HI) • Growing Season Temperature Average (GST) • Prior to Harvest Cool Night Index (PHCI) • Quality	• Regression • Correlation	• Evaluation and analyses • Innovation management • Conclusions

Meteoblue AG (www.meteoblue.com) generously provided high precision historic weather data for the three sites in the Bordeaux region: Listrac – Medoc, Saint Emilion and Pessac.

The Institut des Sciences de la Vigne et du Vin de l'Université de Bordeaux, Unité de Recherche Œnologie (Baugier, 2023) provided data for sugar content, total acidity, and berry weight for Merlot and Cabernet Sauvignon varieties from 1977 to 2022. The wine price data were obtained on the Wine-Searcher website (Wine-Searcher, 2023).

The results obtained in this study are consistent and in line with prior assessemnts and researchs. The bioclimatic indices, Huglin and GST, have demonstrated that the Bordeaux region reached the ideal climate zone for wine production by the end of the 1980s. This privileged condition has been maintained, despite having the Huglin index indicated that it was surpassed in the 2010s.

As expected, an increase in sugar content and consequent reduction in the acidity of the grapes did not negatively impact the quality of the wine. The best vintages (Top 10) during the 1997-2009 period have registered an above average sugar content for the same period, while the total acidity for the aforementioned vintages have been below the average.

2. Literature Review

Wine is a seemingly simple beverage whose characteristics make it different not only from other agricultural commodities, but also from other beverages too. A bottle of *grand vin* can easily exceed a few thousand euros. Premium wines are very susceptible to variations in weather and climate (Storchmann, 2012) which consequently impact their demand and price.

Princeton economics professor and the editor of the American Economic Review, Orley Ashenfelter, has developed an economic model linking auction prices of the mature wines to their age and the weather of such vintages. This model has been particularly successful in its predictions about Bordeaux quality vintages and wine prices (Ashenfelter, 2008) and (Ashenfelter, Ashmore & Lalonde, 1995). The "Bordeaux equation" encompasses several weather data and climate change variables published by the Professor Ashenfelter, which accurately quantifies the relationship between weather and wine prices. According to Ashenfelter, the Bordeaux grand cru wines can differ by a factor of 10 or even more, depending on the quality of the vintage.

Jones & Davis (2000) also conducted an econometric assessment of the market price for 21 of the Bordeaux Crus Classés wines. The main objective was to examine the relationship among the factors which have a direct impact on wine quality and prices. Two important parameters considered in the assessment have been:

a. climate influence on grape composition-acid and sugar levels; and
b. the market price influenced by the grape composition.

The assessment has concluded that, during the harvest, high sugar and low acid levels produce high quality wines-thus higher demand and price.

Baciocco, Davis & Jones (2014) carried out another important study in the Bordeaux region regarding wine quality Vs. climate. The study closely examined the correlation of a large number of climatic variables to vintage quality and rankings. For the rankings, an assessment developed by Borges et al. (2012) was used, called "Consensus Ranking". In order to lessen the potential for bias in overall ratings, the findings from eight different sources (Andy Bassin, Broadbent, Decanter, Sotheby's, Vintage.com, Wine Advocate, Wine Enthusiast, and Wine Spectator) have been pooled. The ranking covers both red and white wines; however, the key focus of this study will be on red wines only.

The Table 2 below shows the Top 10 and the Bottom 10 red wine vintages for the 1961-2009 period, taken from the Consensus Ranking and presented in order from best to worst.

Table 2. Top 10 and Bottom 10 red wine vintage ranking of Bordeaux region from 1961 to 2009

TOP 10 VINTAGE		**BOTTOM 10 VINTAGE**	
YEAR	RANK	YEAR	RANK
1961	1	1980	40
2009	1	1991	40
2000	3	1984	42
1982	4	1968	43
2005	5	1963	44
1990	6	1965	44
1989	7	1977	46
1995	8	1969	47
1986	9	1974	48
1985	10	1972	49

Ashenfelter and Storchamann (2016) probed into economic implications of the climate change on wine quality, prices, costs, and profits. According to their study, a simple conclusion could not be reached. Based on the current weather and climate conditions, the temperature increase during the growing season can have both positive and detrimental effects. Furthermore, they concluded that climate change could even bring out the winners and losers among the winemakers. The winners could be the ones closely located to the North and South Poles, or within the regions adjacent to the frontiers of the commercial viticulture, such as Germany in the Northern Hemisphere and Patagonia or Tasmania in the Southern Hemisphere. The losers, on the other hand, could well be Spain and the South of France. The study has also portrayed the adaptability of the grape growers and winemakers, over the course of time, in connection with various climate shifts and changes.

Jobien-Poirier (2020) conducted an extensive on-line survey with 122 Canadian winegrowers in four main provinces: Ontario, British Columbia, Quebec and Nova

Scotia. The survey was aimed to measure via established tools, the environmental values, subjective and objective of Climate Change knowledge, Climate Change skepticism and uncertainty, beliefs in anthropogenic Climate Change and the perceptions of the impacts of the Climate Change. The majority of 60% of the winegrowers considered that Climate Change has had both positive and negative impacts on their vineyard and winery operations. Only 8% of the winegrowers believed that Climate Change had no influence on their operations, as shown in Figure 3.

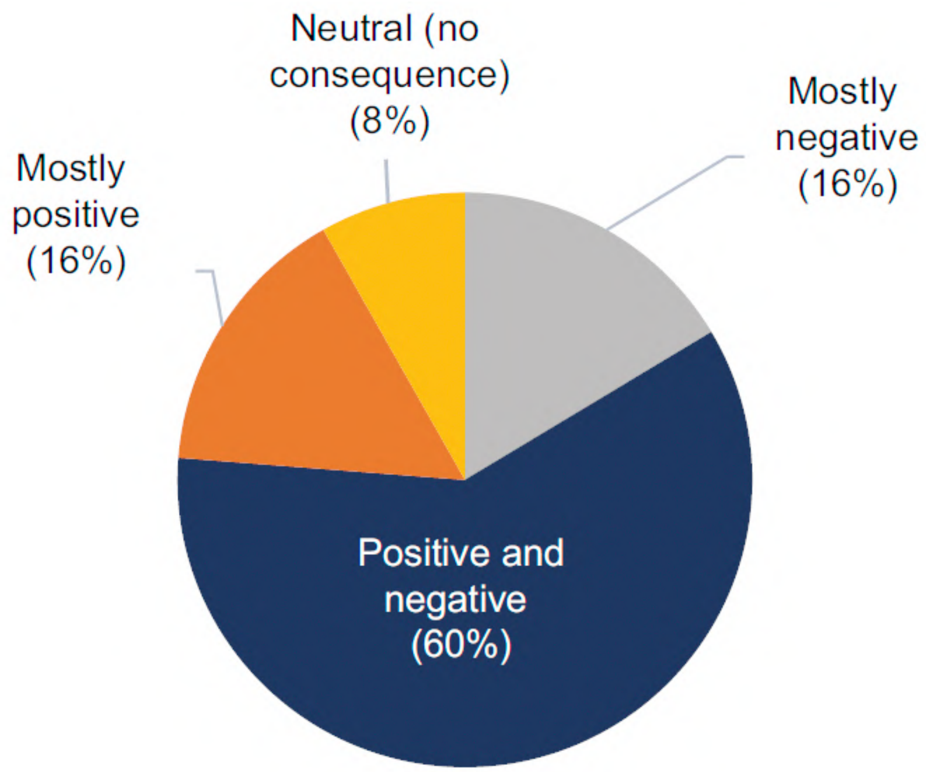

Figure 3. Consequences of climate change perceived by Canadian winegrowers
Source: Jobien-Poirier (2020)

The investigation has also concluded that the winegrowers have a pro-environmental conception. As per knowledge of the Climate Change, it was considered to be moderated. An important point to be highlighted in this survey is the uncertainty of the winegrowers regarding the specific effects of Climate Changes on their operations.

Figures 4 and 5 illustrate the benefits and disadvantages of the Climate Changes perceived by the Canadian winegrowers.

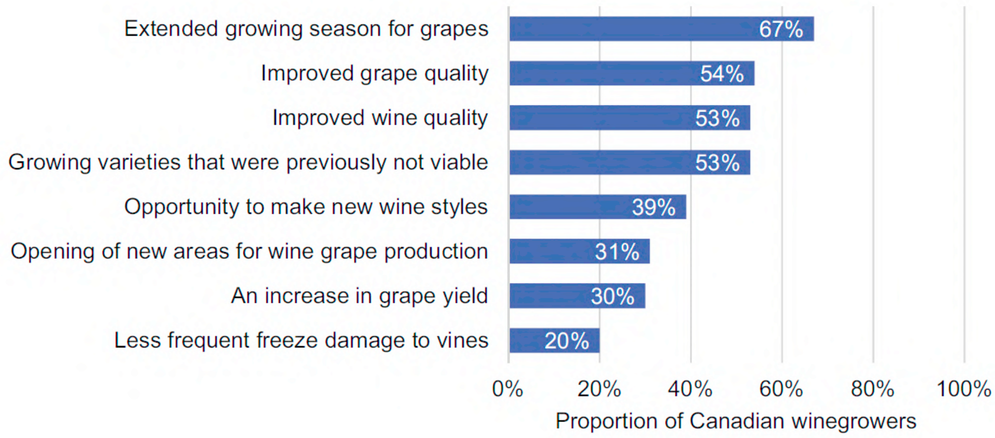

Figure 4. Perceived benefits of climate change for the wine industry
Source: Jobien-Poirier (2020).

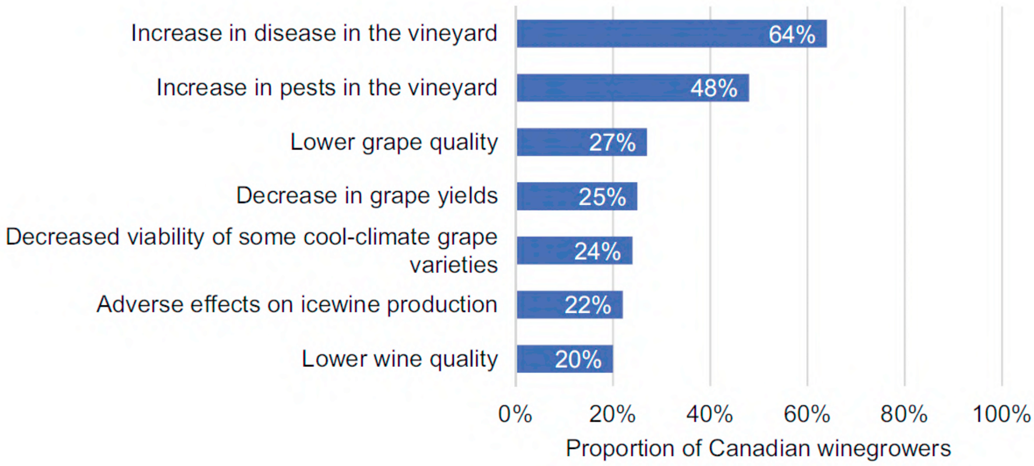

Figure 5. Perceived disadvantages of climate change for the wine industry
Source: Jobien-Poirier (2020)

The study has also concluded that rather than reinforcing the existence and the veracity of climate change and anthropogenic contribution, there is also the need to document and inform the effects and impacts of the Climate Change on the winegrowers. Another important conclusion of the study is the need of collaboration between the main stakeholders, especially between winegrowers and the Climate Change experts.

Among agricultural activities, the cultivation of winegrapes is one of the most sensitive to climate and weather changes. The production of winegrapes for premium wines occurs in a narrow range of climatic conditions and climate change has pushed the wine industry to new limits. (Mozell & Thach, 2014).

Mozell & Thach (2014) did an extensive literature review to raise the impact of Climate Change and potential challenges in the global wine production. The study has focused on global warming causes, grape variety and premium winegrape regions, quality of wine, grape chemistry, vineyard pests and diseases and quality of oak. The study has concluded that climate is changing and has direct impacts on both vineyard management and wineries. Such evidence suggests that Climate Change have direct impact on winegrape and wine production. It affects not only the grapevine's physiology and biochemistry, but also the current wine making production methods.

The study proposed a series of practical solutions to mitigate the negative impacts and how the global industry should adapt to the Climate Change. Some of those proposed solutions concerned the vineyards-existing and newly planted, and the wine production itself. Among the suggestions some of them have been:

- canopy management to optimize the soil-water balance, providing additional shade in order to reduce sugar and increase acidity;
- cooling techniques such as vine orientation/trellising practices and water efficient misters to counterbalance heat intensification in a vineyard. Optimised training techniques and row orientations to reduce sunlight exposure;
- as for pests and diseases, it suggested the Integrated Pest Management and the use of biological control agents;
- harvest and swift delivery (transportation) of the berries during the night;
- to offset warmer temperatures in the winery, utilizing cooling system to assure completed primary and malolactic fermentation and the use of antimicrobials and antioxidants;
- as for higher sugar levels, the study suggested the employment of sugar reducing techniques such as ultrafiltration and reverse osmosis;
- promote microbiological/microbial stability to offset the reduction of acidity;
- as for early harvest and lower acid level in white wines, it suggested leaving it on their lees longer.

However, the study also emphasised the solutions may not be applicable in all cases and socio-economic issues, politics, and regulations can also affect the wine industry just as much as climate changes.

It also suggested that the future of the wine industry will depend on effective and concrete actions. These actions will be crucial for the survival of the wine industry.

Although this study (Jones & Davis, 2000) focuses on the second half of the last century, it brings important information and conclusions about the influence of the climate change in the Bordeaux region. The study analysed the impacts on Cabernet Sauvignon and Merlot grapes regarding phenology and composition of the grapes and the wine quality. It concluded that, mainly for the last two decades investigated, a combination of climatic factors has had a significant influence on the phenology, quantity, and quality of the Bordeaux vintages-both positive and negative.
Table 3 shows the figures of the vineyard phenology, vintage quality, compositional parameters of acid and sugar levels, and berry weights for Merlot and Cabernet Sauvignon for the period of 1952-1997 in Bordeaux.

Table 3. Bordeaux reference vineyards phenology, production, composition, and quality descriptive statistics for Cabernet Sauvignon and Merlot varieties.

Variable	N	Mean	Std. Dev.	Max	Min	Range
Budburst (estimated, days)	49	23-Mar	18	24-Apr	9-Feb	75
Floraison (days)	46	12-Jun	8	27-Jun	23-May	35
Veraison (days)	46	17-Aug	9	3-Sep	31-Jul	35
Harvest (days)	46	2-Oct	9	17-Oct	3-Sep	44
Budburst to Floraison (days)	46	81	18	139	51	88
Budburst to Veraison (days)	46	148	19	206	115	91
Budburst to Harvest (days)	46	193	19	246	162	84
Floraison to Veraison (days)	46	67	3	76	60	16
Floraison to Harvest (days)	46	112	6	125	103	22
Veraison to Harvest (days)	46	45	5	58	34	24
Cab. Sauvignon TA (g/L)*	26	5.2	1.0	8.2	3.8	4.4
Cab. Sauvignon sugar (g/L)	26	190	11.3	214	168	46
Cab. Sauvignon wt/100 berries (g)	26	120	13.1	162	104	58
Merlot total acidity (g/L)*	26	4.6	0.9	7.2	3.2	4.0
Merlot sugar (g/L)	26	203	13.7	232	176	56
Merlot weight per 100 berries (g)	26	147	17.6	186	120	66
AOC red wine production (hL/year)	60	2085020	1532183	5748688	370978	5377710
Quality (scale 1-7)	57	4.7	1.9	7	1	6

*Total Acidity is measured in grams of H_2SO_4 per liter.

Source: Jones & Davis (2000)

Figure 6 shows the trends for the phenology events of budburst, floraison, véraison and harvest dates. Harvest date is the only event that had a clear and significant trend for the time period evaluated, 1952-1997

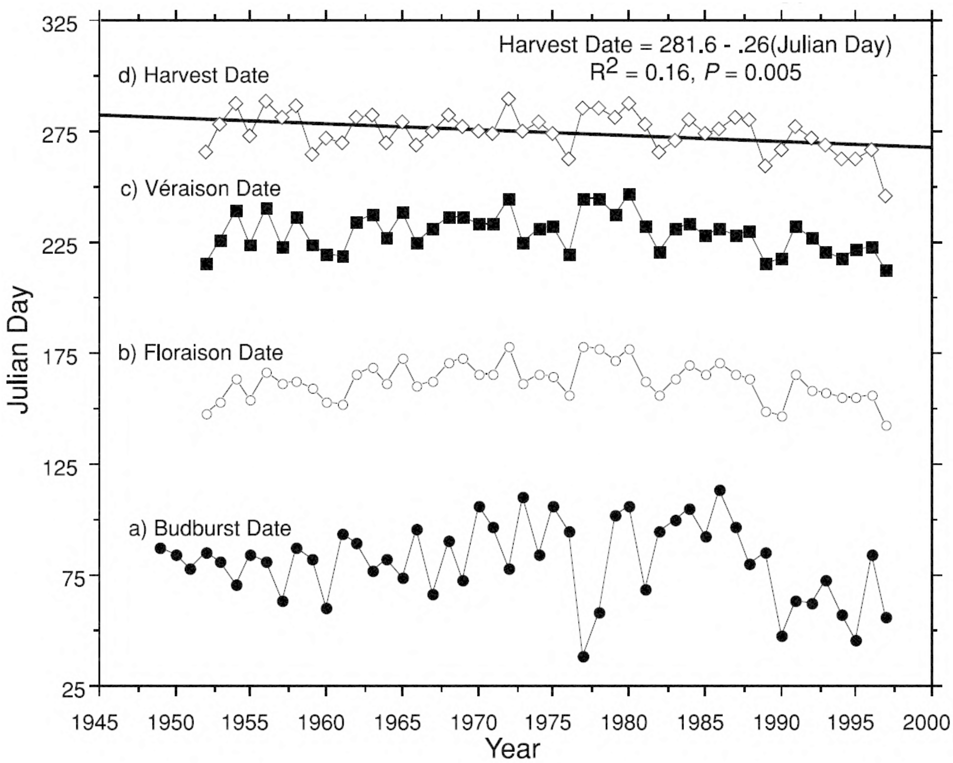

Figure 6. Time series of the major phenological events or the Bordeaux reference vineyards
Source: Jones & Davis (2000)

The study concluded that in the last two decades, approximately between 1977 and 1997, in Bordeaux, the climate change has had a significant impact on the phenology of both grapes-Merlot and Cabernet Sauvignon.

An ample interval of time of the reporting period, 1977-1997, coincided with the IPCC (Intergovernmental Panel on Climate Change) (2014) assessment that the period between 1983 and 2012 was the warmest 30-year interval in the last 1,400 years in the Northern hemisphere.

The study has also highlighted the possibility that, considering all the phenomena and parameters evaluated, the Merlot grape could be more phenologically and climatologically sensitive to changes than Cabernet Sauvignon. Another important conclusion the study stressed, was that the sugar to acid ratios for both grapes has had an impact on Bordeaux wine quality.

The study carried out in the two regions of the Czech Republic, Bohemia and Moravia (Navrátilová et al., 2020), had showed that the air temperature affected the sugar content of the grape. The study concluded that the sugar content in the grapes had increased over the years, showing a steady growth trend for the investigated period of 20 years, from 2000 to 2019, in the two regions surveyed.

Figure 7 shows the curves and trends of the sugar content over the years. The sugar content is measured in °NM, degrees of standardized mustmeter.

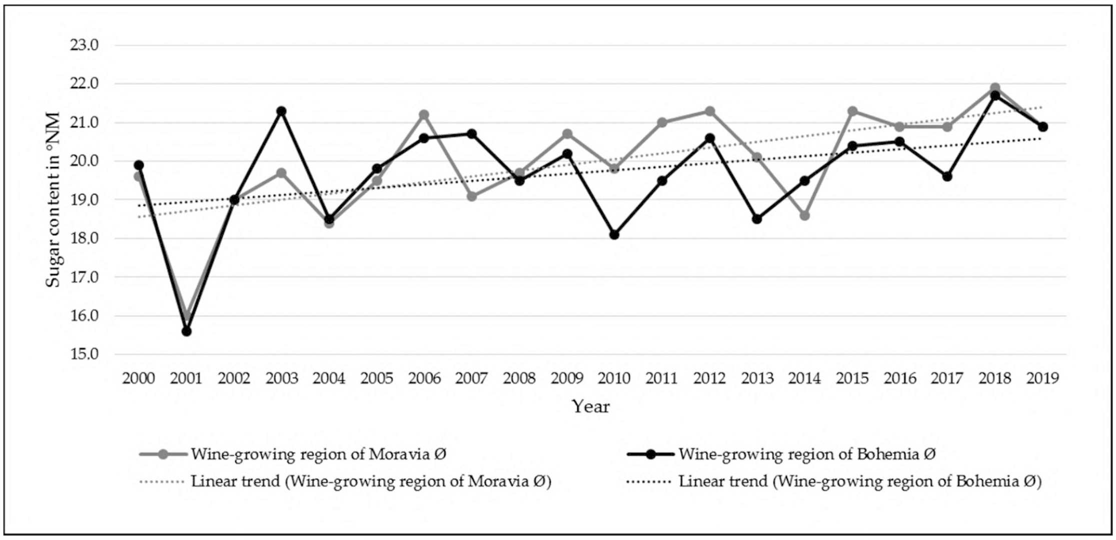

Figure 7. Development of the sugar content of grapes in Mondavia and Bohemia, in the Czech Republic, during the years 2000 to 2019
Source: Navrátilová et al. (2020)

The Huglin Index and the Winkler Index were utilized to determine the relationship between climate and sugar content in grapes. Although the Huglin Index and the Winkler Index described the impact of the climate change in a statistically substantial way, the air temperature Vs. sugar content, the Huglin Index proved to be more apposite than the Winkler Index in both wine regions, Moravia and Bohemia.

The Huglin Index is a bioclimate heat index for vineyards and one of the main tools used in viticulture. Essentially, the Huglin Index is the sum of the minimum and maximum temperature above 10°C, from April 1 to September 30 in the Northern Hemisphere. The Huglin Index considers that the daytime temperatures are critical in growth of most vines, and consequently, it is correlated to grape composition during the harvest (ADVICLIM, 2015).

$$\text{Huglin Index} = \text{K} \times \sum\left(\frac{Tmean+Tmax}{2} - 10\right)$$

K is the latitude constant.

The Huglin Index showed a higher correlation rate, 0.82, regarding the effects of the air temperature on sugar content in grapes. Figure 8 shows the data and the linear regression equations for both sites. It is important to emphasise that the sugar content plays an important role in the classification and quality of the wines.

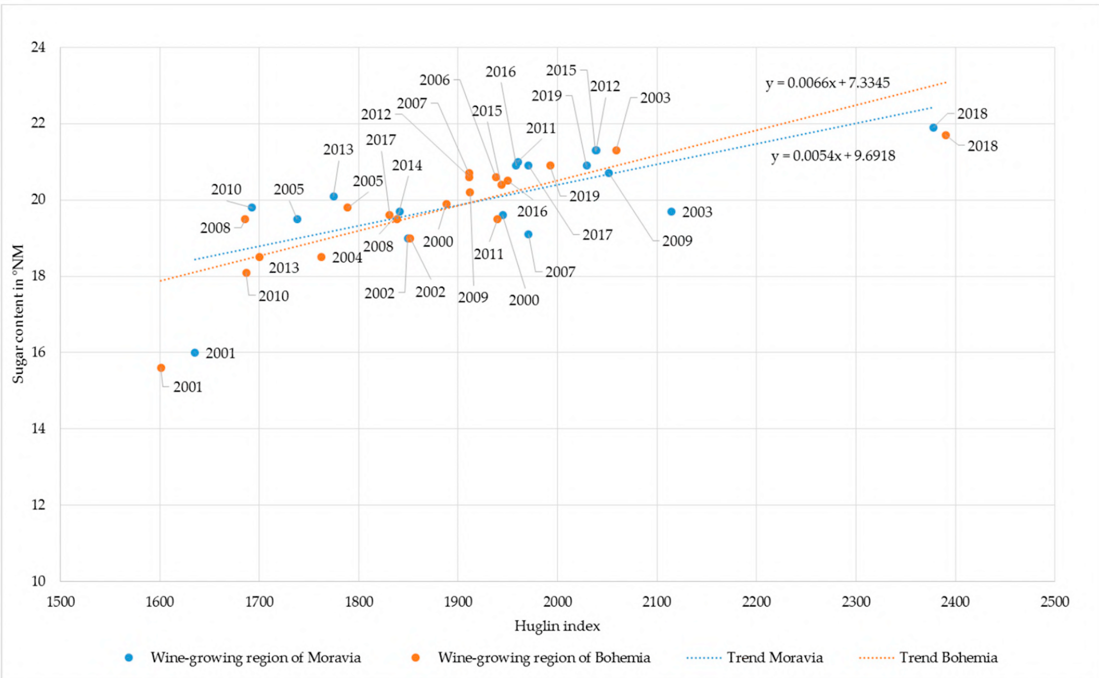

Figure 8. Relationship between Huglin Index and the sugar content of grapes in Moravia and Bohemia, in the Czech Republic
Source: Navrátilová et al. (2020)

Another interesting study was developed by Comte, Schneider, Calanca & Rebetez (2022) within vineyards alongside the Lake Neuchatel in Switzerland. As for the study in the Czech Republic (Navrátilová et al., 2020), it had investigated the impact of climate change in the phenology and typicity of wines using Huglin Index, but Comte et al. (2022) also encompassed other bioclimatic indices. The growing season temperature average (GST) used by Jones, White, Cooper & Storchmann (2005) describes the suitability for growing specific grape varieties, considering the average temperature of the growing season. It is calculated by taking each month average of the seven-month growing season:

April 1st to October 31st, in the Northern Hemisphere; and October 1st to April 30th, in the Southern Hemisphere.

The third index, developed by Comte et al. (2022) was the Prior to Harvest Cool Night index – PHCI. Instead of the Cool Night index (CI) that is based on October temperatures in the Northern Hemisphere, PHCI is calculated based on the minimum temperature (T_{min}) during the 30-day period prior to the harvest. It is considered to be more accurate since the harvest not always takes place in the month of September. The formula to calculate the PHCI is:

Prior to Harvest Cool Night Index : $1/30 \sum_{Hd-30}^{Hd} Tmin$

Where H*d* is the annual average date of the harvest period.

Comte et al. (2022) came to important conclusions, showing the impact of the Climate Change in the vineyards alongside Lake Neuchâtel chiefly over the last 50 years.

The trends of the growing season temperature average, GST (Jones et al., 2005), T*min* is showed in Figure 9. The regression for the period from 1974 to 2019 shows a significant increase of 0.55ºC/decade^{-1} for the GST. According to the GST proposed by (Jones et al., 2005), the PN red band in the Figure 8 indicates a T*min* suitable for the Pinot Noir grape and MN blue for Merlot, with a ± 0.2 – 0.5ºC of error margin.

According to the classification proposed by (Jones et al., 2006), the climate in the Neuchâtel region was cooler during the 1970s, with an average GST of 14.2ºC. Due to the increased temperature, the climate during the 2010s is classified as an intermediate, with an average GST of 16.3ºC.

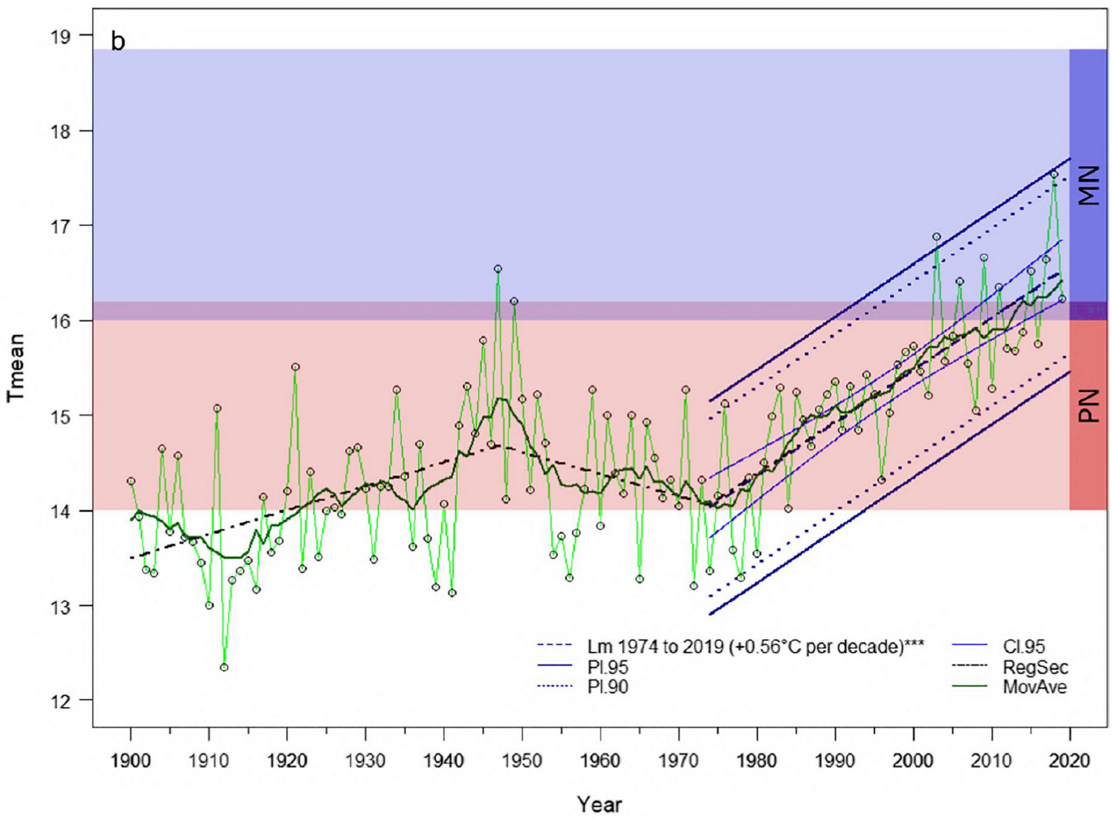

Figure 9. Trends in the growing season temperature averages (GST) at the Lake Neuchâtel station from 1900 – 2019
Source: Comte et al. (2022)

Analogous to the GST trends, the Huglin Index has had significant changes in the evaluated period, Figure 10. In the 1970s, the main Huglin Index values were in the range of 1300 to 1500. According to (Huglin & Schneider, 1998), theoretically, these values were at the bottom limit of the index for vine growth. The climate in this scenario was considered to be very cool. However, over the past 40 years, the climate shifted from very cool to moderate, resulting in the increase in the Huglin Index by approximately 400. The computed segmented regression for the period from 1972 to 2019 had been characterised by an increase of 103 ± 15.1 per decade.

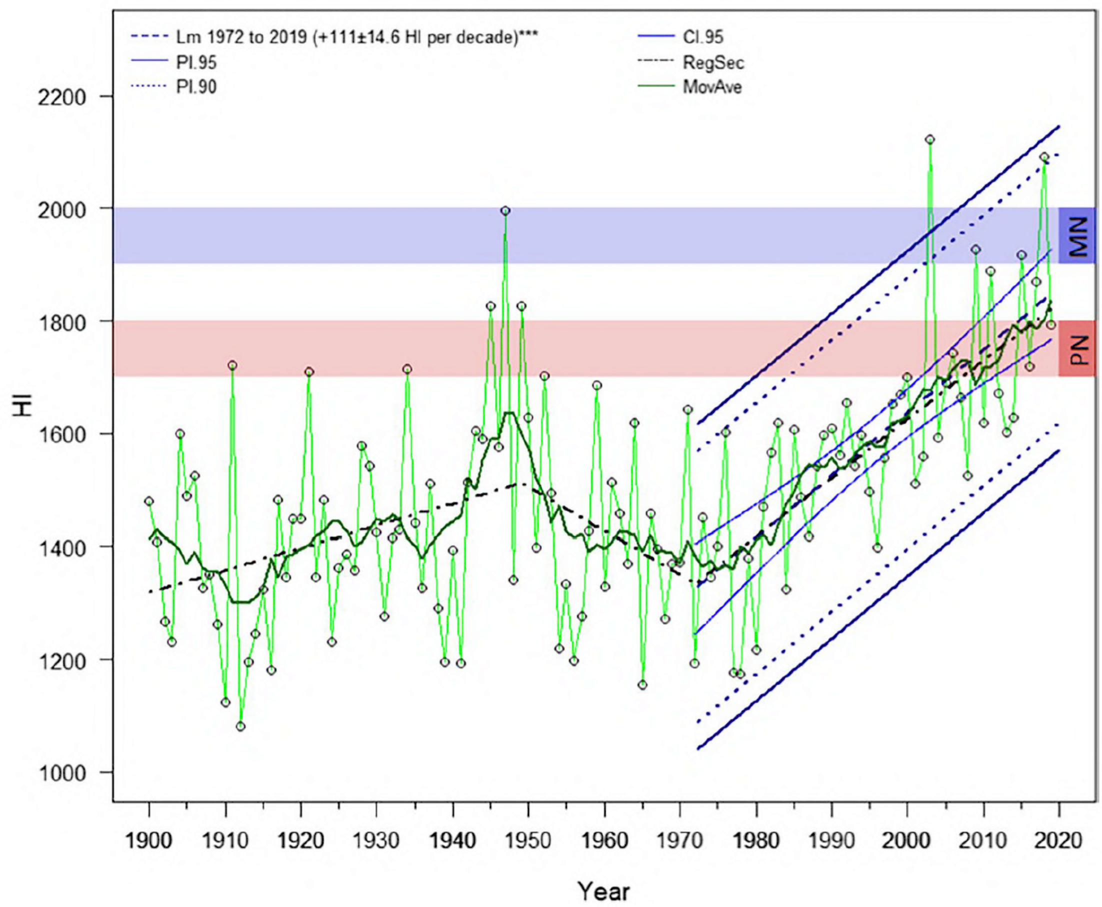

Figure 10. Trends in Huglin Index at the Lake Neuchatel station from 1900 – 2019
Source: Comte et al. (2022)

Considering the growing season temperature average index, GST, and the indicator for grape variety suitability, the study has concluded that the climate in the Lake Neuchâtel region has become more suitable for Merlot than Pinot Noir. Furthermore, the rather late budburst of Merlot is an advantage when compared to Pinot Noir since the spring frost risk is quite lower.

It means that the winegrowers need to mitigate the impacts of the climate change and to implement adaptations to vineyards and wine production, especially of Pinot Noir. The increase of the Huglin Index during the same period by more than 400 units, corroborates with the GST evaluation and outlines potential future problems when it comes to the increase of sugar content in Pinot Noir. One practical solution suggested by the study was to grow Pinot Noir at higher altitudes.

The study also concluded that PHCI is more appropriated than CI to evaluate the impacts of Climate Change in vineyards and wine production, since CI no longer represents the real conditions of cool nights in the pre-harvest period. PCHI has increased in a ratio of 0.97°C per decade and indicates that the Lake Neuchâtel's region will face moderate night conditions before the harvest.

According to a study carried out in France, Germany, and Italy, the winemaking could implement different tactics to adapt to the climate change, which would depend on the local climate system (Battaglini et al., 2009).

In this study, three macro-climatic regions were evaluated to verify the perception of the climate change impacts: Atlantic, transition to Continental and Mediterranean. Most winegrowers, in the aforementioned countries, have noticed changes in the climatic conditions in recent decade, as shown in Figure 11.

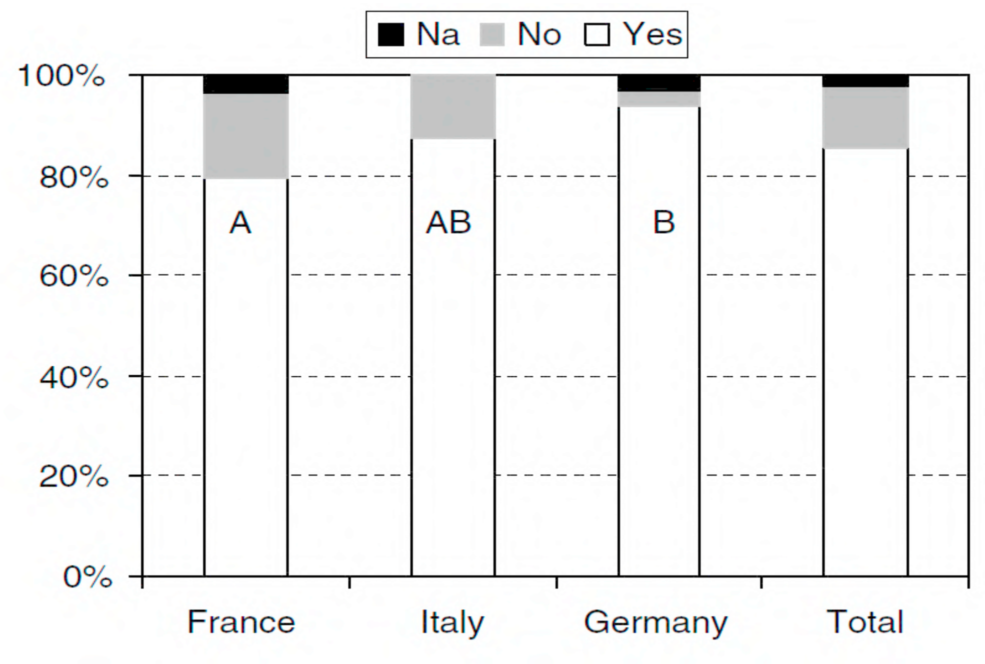

Figure 11. Fraction of winegrowers (%) who have (Yes) or have not (No) perceived a climate change in the last 10 – 20 years
Source: Battaglini et al. (2009)

Figures 12 and 13 show that the majority of the winegrowers in the three countries discerned an impact in wine quality, yet in some other regions, the effect was rather positive. They also perceived an increase in pests and diseases.

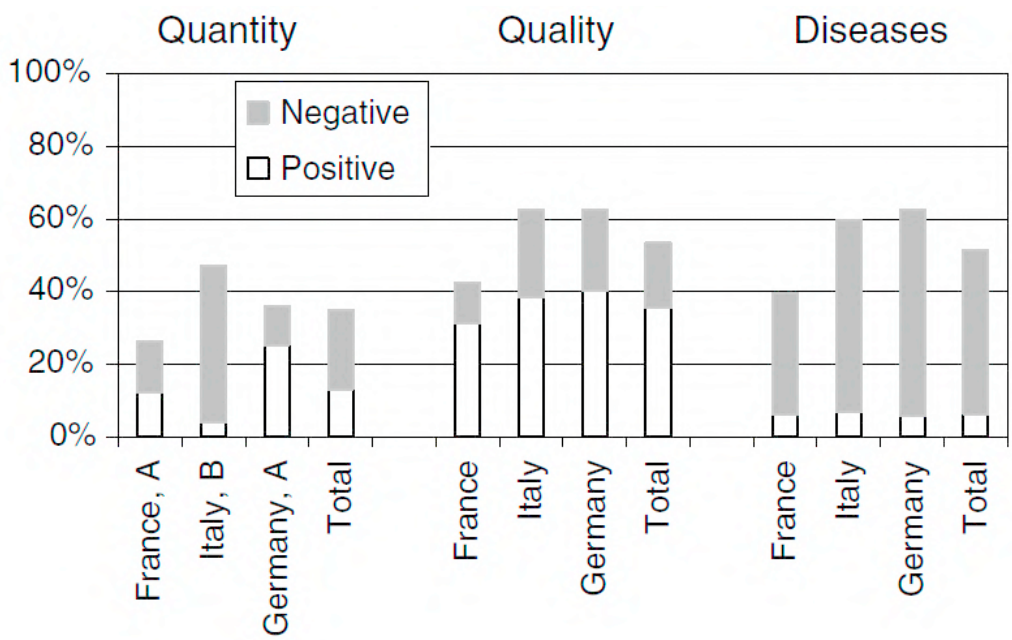

Figure 12. Fraction of winegrowers (%) who have (Yes) or have not (No) noticed an impact on quantity, quality, and diseases
Source: Battaglini et al. (2009)

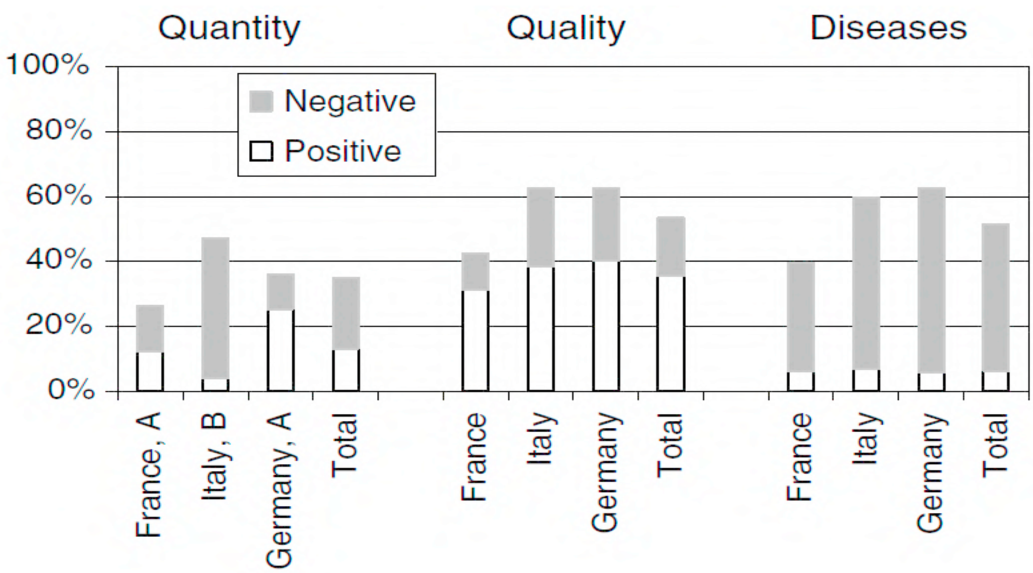

Figure 13. Perceived positive and negative influence on quantity, quality, and diseases 9%)
Source: Battaglini et al. (2009)

As for the possibility to grow different grape varieties in case the weather becomes unsuitable for current varieties, approximately 50% had no plans to change the varieties. In the study carried out in Canada, it was also concluded that information and transfer of technical knowledge from scientific research to practice, are vital for adapting to challenges and impacts imposed by the climate change.

Another important parameter that must be taken into consideration, when assessing the impacts of the Climate Change, is the large diversity of climates (Schultz, 2016). The winegrapes are grown on six out of seven continents between the latitudes 4º and 51º in the Northern Hemisphere and 6º and 45º in the Southern Hemisphere. Wine producing regions can be located within the following climates: oceanic, warm oceanic, transition temperate, continental, cold continental, Mediterranean, subtropical, attenuated tropical, and arid climates. According to Schultz (2016), two scenarios are expected from the climate change during the grape-ripening: warmer and dryer & warmer and moister. The red and white grapes have different responses to these scenarios. In order to ensure a sustainable product, the strategies to face the impacts and effects of the climate change must take, by all means, these particularities into an account. Schultz emphasizes the importance of incorporating other cofactors, in addition to temperature summations, such as day-night variations, sunshine hours and water availability in the grape quality formation.

The studies and research mentioned above confirmed that Climate Change has been impacting the wine industry for decades, both in vineyards and in wine production. Impacts can be positive or negative, depending on several factors, such as local specificities and grape varieties.

The gathered data and information will be subjected to statistical usage for further evaluation, analyses, and conclusions.

3. Field of Study

3.1. Introduction

To evaluate the impact of Climate Change in the wine Bordeaux region, a quantitative method was applied to estimate the effect of meteorological parameters in the typicity, quality and economic environment of the Bordeaux wines. As for the grape, the parameters such as sugar content, total acidity and berry weight were utilized to calculate the correlations. Bordeaux, due to its importance on a global scale, has been the object of study for several years by renowned researchers such as Ashenfelter et al. (1995), Ashenfelter (2018) and Jones & Storchmann (2001). This study aims to focus and complement research and analysis developed by these authors and others in the recent past in the Bordeaux wine industry, using more up-to-date data. The main objective is to look at what has changed, if the conclusions and assumptions are still valid, and how it can be extrapolated for the future, considering the climate change.

Comte et al. (2022), Jones & Davis (2000), Tonietto & Carbonneau (2004) and other researchers and scientists have recommend bioclimatic indices that are distinctive of the variability of the viticultural climate worldwide, concerning needs of varieties, vintage quality (sugar, acidity, aroma, etc) and typeness of the wines. Table 4 shows the bioclimatic indices applied in this study and their source.

Table 4. Bioclimatic indices and literature sources

Index name and abbreviation	**Period**	**Source**
Huglin Index (HI)	1 Apr. to 30 Sep.	Huglin (1978)
Growing season temperature average (GST)	1 Apr. to 31 Oct.	Jones et al. (2005)
Cool night index (CI)	September	Tonietto & Carbonneau (2004)
Prior to harvest cool night index (PHCI)	30 days before harvest	Comte et al. (2022)

Figure 14 shows the wine map of Bordeaux. Basically, the study will utilize meteorological data from three sites, one on the left bank, one on the right bank, and one in the southwest of Bordeaux.

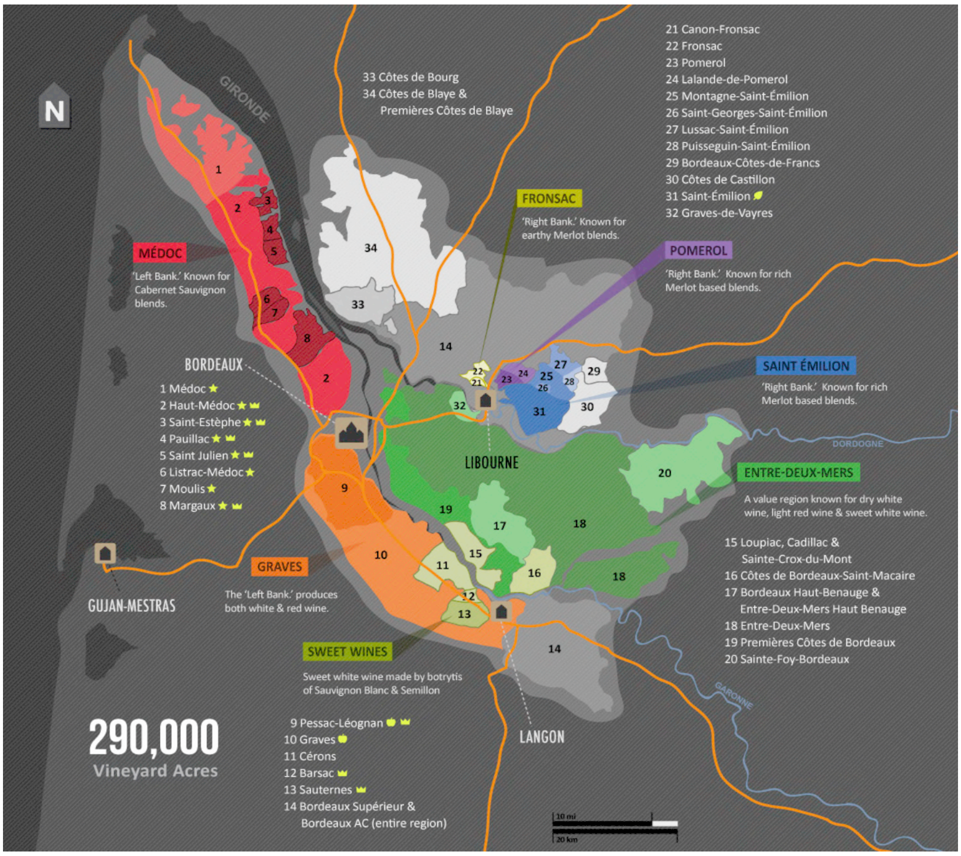

Figure 14. Map of Bordeaux wine region
Source: Wine Folly. Retrieved June 9, 2023, from https://winefolly.com/tips/superieur-cheap-bordeaux-wine/

3.2. Methodology

To treat the meteorological data, bioclimatic indices and grape properties and their correlations, the quantitative analysis was utilized. According to the research and studies mentioned in the literature review section, insofar, the climate change has had a positive impact on the Bordeaux region.

The meteorological data were kindly provided by Meteoblue AG for three sites: Listrac – Medoc, Saint Emilion and Pessac. Previous study (Lecocq & Visser, 2006) has revealed that only one weather station is enough for macro surveys in Bordeaux region, whereas the additional stations wouldn't significantly increase the robustness of the study. A preliminary analysis will be done to guarantee that the parameters and indices of this study are estimated and calculated having just one meteorological source.

Data for physiology and biochemistry, sugar content, total acidity, and berry weight were provided by the *Université de Bordeaux* (Baugier, 2023) regarding the 1977-2022 period.

Although the Meteoblue AG meteorological data span over several decades, the period from 1977 to 2022 was chosen, since the data from the *Université de Bordeaux* were available only for this period.

3.2.1. Bioclimatic analysis

In the late 1970s, the French scientist Pierre Huglin developed a bioclimatic heat index (Huglin, 1978) for vineyards. It was developed for growing cultivated grapes on flatlands in France to describe the thermal availability in different territories. Initially, it was known as heat sum index. Nowadays, it is well known as "Huglin Index" and it has been shown to be an effective tool when it comes to the viticulture. It has gained more prominence with the change in the climate and has been widely utilized in the wine industry ever since.

Huglin Index estimates and evaluates how suitable certain regions are regarding heat accumulation in order to successfully grow certain types of grapes in a particular area for a long period of time. In other words, the ability of grapevines to produce ripe fruits for wines. There is a correlation between the thermal availability and the quality of the wine in certain regions.

Essentially, the Huglin Index is the sum of the minimum and maximum temperature above 10°C, from April 1 to September 30, in the Northern Hemisphere, and from October 1 to March 31, in the Southern Hemisphere.

The formula to calculate the Huglin Index is:

$$HI = K \cdot \sum_{01.04.}^{30.09.} \left(\frac{T_{\text{mean}} + T_{\text{max}}}{2} - 10 \right)$$

Tmean = daily mean temperature

Tmax = daily maximum temperature

Baseline temperature = 10 °C

K: dependent on the latitude of the location

All days from 1 April till 30 September

K coefficient expresses the mean day length in relation to the latitude according to the Table 5. Bordeaux is located at latitude 44.8º, K=1,04.

Table 5. K coefficient as a function of latitude

Latitude	K
40,1º - 42,0º	1,02
42,1º - 44,0º	1,03
44,1º - 46,0º	1,04
46,1º - 48,0º	1,05
48,1º - 50,0º	1,06

Table 6 summarizes the Huglin Index values and ranges for grape varieties to produce high-quality wines. The Huglin Index will be used to verify the correlation and the impact on properties and quality of Merlot and Cabernet Sauvignon varieties, such as sugar content, total acidity and berry weight in the Bordeaux region.

Table 6. Huglin index values for several varieties of grapevine in order to produce high-quality wines

Huglin – Index (HI)	Grape Variety
H < 1500	Not recommended for cultivation
1500 ≤ H <1600	Muller-Thurgau, Blauer Portugieser
1600 ≤ H < 1700	Pinot Blanc, Grauer Burgunder, Aligoté, Gamay Noir, Gewurztraminer
1700 ≤ H < 1800	Riesling, Chardonnay, Silvaner, Sauvignon Blanc, Pinot Noir, Gruner Veltliner
1800 ≤ H < 1900	Cabernet Franc
1900 ≤ H < 2000	Chenin Blanc, Cabernet Sauvignon, Merlot, Semillon, Welschriesling
2000 ≤ H < 2100	Ugni Blanc
2100 ≤ H < 2200	Grenache, Syrah, Cinsault
2200 ≤ H < 2300	Carignan
2300 ≤ H < 2400	Aramon

Huglin (1978, 1986) and Tonietto & Carbonneau (2004) have also classified the class of the climates according to the range of temperatures. Table 7. shows the climate classification, from very cool to very warm, and their temperature ranges respectively.

Table 7. Huglin index classes

Climate Class	Values (ºC)
Very cool	≤ 1500
Cool	> 1500 ≤ 1800
Temperate	> 1800 ≤ 2100
Temperate-warm	> 2100 ≤ 2400
Warm	> 2400 ≤ 3000
Very warm	> 3000

Growing season temperature (GST) might provide the most advanced single index for identifying region climates. GST used by (Jones et al., 2005) describes the suitability for growing particular grape varieties taking into an account the average temperature of the growing season, from 1 April to 31 October in the Northern Hemisphere.

The formula to calculate the growing season average temperature is:

GST= Avg (*Tmean*)

All days from 1 April till 31 October

Table 8. Class limits of climate as a function of the temperature

Growing Season Average Temperature (GST)	
Temperature	**Class limits**
< 13 ºC	Too cold
13 – 15 ºC	Cool
15 – 17 ºC	Intermediate
17 – 19 ºC	Warm
19 – 21 ºC	Hot
21 – 24 ºC	Very hot
> 24 ºC	Too hot

The third index, cool night index (CI) is an indicator of night temperature conditions during maturation. According to Tonietto & Carbonneau (2004), the air temperature plays a key role in grape maturation, including acidity, aroma, and anthocyanins. CI improves the evaluation on the grape qualitative potentials, particularly regarding secondary metabolites (polyphenols, aromas) in grapes. The daily temperatures influence the acidity, aroma, and coloration, but the effect of the conditions of cool night temperatures is even more pronounced. Night temperatures below 15 °C increase acidity. CI is based on September temperatures.

The formula to calculate the growing season average temperature is:

CI= Avg (*Tmin*)

Month of September

With the advent of the climate change, the CI no longer reflects the reality with the current harvest period (Comte et al., 2022). Some Bordeaux wineries start their harvest as early as the mid or end of August (CIVB, 2023). To reflect the new reality, the prior to harvest cool night index (PHCI) will be estimated. It is calculated by taking into consideration changes in harvest date. It is projected 30 days prior to the harvest date and no longer only in the month of September.

3.2.2. The data from Meteoblue AG

Meteoblue AG has provided historic weather data for the three sites already mentioned: Listrac – Medoc, Saint Emilion and Pessac. These are simulation data with high precision (stored forecasts, not measurements). Usually, they are more precise than measurement data from a station which is more than 10-50 km away from the desired location. They will be 100% complete (which very seldom happens to measurements), much more detailed (based on hourly intervals), available since 1960, and valid also for places without measurements. The historic weather data for the three-station utilized in the study are in the period from January 1977 to December 2022. Data from 2023 were not included, since the growing season data are not yet available, only from October 2023 onwards.

Table 9 shows an example of how data are made available by the Meteoblue AG. Historic weather data based on hourly intervals, for the following parameters: air and soil temperatures, radiation and, precipitation. This study will focus on air temperature.

Table 9. Hourly intervals for one day, for the air and soil temperatures, radiation, and precipitation

Location	**Listrac-Médoc**	**Listrac-Médoc**	**Listrac-Médoc**	**Listrac-Médoc**
Lat	45	45	45	45
Lon	-0,75	-0,75	-0,75	-0,75
Asl	29,740458	29,740458	29,740458	29,740458
Variable	Temperature	Sunshine Duration	Precipitation Total	Temperature
Unit	°C	Min	mm	°C
Level	2 m elevation corrected	Sfc	sfc	sfc
Resolution	Hourly	Hourly	hourly	hourly
Timestamp	**Temperature [2 m]**	**Sunshine Duration**	**Precipitation Total**	**Temperature Soil**
1977-01-01T00:00:00	12,0233135	0	1,3	-3,41
1977-01-01T01:00:00	11,953314	0	1,1	-3,43
1977-01-01T02:00:00	11,293313	0	0,2	-3,69
1977-01-01T03:00:00	10,893313	0	0,3	-3,63
1977-01-01T04:00:00	9,653314	0	0,5	-3,46
1977-01-01T05:00:00	8,963313	0	0,6	-3,38
1977-01-01T06:00:00	9,003313	0	0,3	-3,58
1977-01-01T07:00:00	8,683313	0	0,2	-4,11
1977-01-01T08:00:00	8,893313	0	0,2	-4,8
1977-01-01T09:00:00	8,883313	0	0,1	-5,17

1977-01-01T10:00:00	8,2733135	17,5867	0	-5,13
1977-01-01T11:00:00	8,623313	40,606064	0	-2,96
1977-01-01T12:00:00	11,323314	15,757578	0	-1,16
1977-01-01T13:00:00	10,413313	16,363636	0,6	-0,11
1977-01-01T14:00:00	10,143313	32,727272	0,4	1,27
1977-01-01T15:00:00	10,053313	35,151512	0,3	1,79
1977-01-01T16:00:00	9,653314	43,0303	0	1,41
1977-01-01T17:00:00	9,463313	44,242424	0	-0,4
1977-01-01T18:00:00	9,303313	49,696968	0	-2,88
1977-01-01T19:00:00	7,683313	28,036364	0	-4,44
1977-01-01T20:00:00	7,913313	0	0	-4,32
1977-01-01T21:00:00	8,153314	0	0	-4,56
1977-01-01T22:00:00	7,793313	0	0	-4,51
1977-01-01T23:00:00	7,733313	0	0,6	-4,55

Source: Meteoblue AG. Retrived June 9, 2023, from https://www.meteoblue.com/pt/tempo/semana/matup %c3%a1-airport_brasil_7731257

3.2.3. The data from the Université de Bordeaux

The *Institut des Sciences de la Vigne et du Vin de l'Université de Bordeaux, Unité de Recherche* Œnologie (Baugier, 2023) started recording data regarding physiology and biochemistry of the wine grapes grown in Bordeaux in the early 1950s, but only the data from 1977 onwards have been made available on their website. The vineyards are located in Saint Emilion, Pauillac, Margaux, Pessac-Léognan and Entre-Deux-Mers. The recorded data are for the two main varietals grown in the Bordeaux region, Merlot and Cabernet Sauvignon, from 10 to 15 of the top châteaux (Jones & Davis, 2000). The names of the châteaux are confidential. The parameters continuously recorded and made available throughout this period, 1977-2022, have been sugar content (g/l), total acidity (g/l H_2SO_4) and berry weight (g per 100 units). Table 10 shows the data for Merlot and Cabernet Sauvignon varieties. The data for the year 2011 were not available.

Table 10. Sugar, Total Acidity and Weight Grape for Merlot and Cabernet Sauvignon in the Bordeaux region

YEAR	SUGAR (g/l)		TOTAL ACIDITY (g/l H2SO4)		WEIGHT (g)	
	MERLOT	CS	MERLOT	CS	MERLOT	CS
1977	181	170	6,1	7,0	148	118
1978	203	193	5,7	6,1	128	119
1979	196	174	5,1	6,1	140	116
1980	196	181	5,2	5,8	134	110
1981	192	186	4,6	5	138	110
1982	212	200	4,3	4,7	140	116
1983	204	195	4,8	5,2	137	115
1984	195	185	5,6	6,0	145	122
1985	220	200	4,3	4,6	149	117
1986	208	199	4,1	4,3	135	115

1987	207	184	4,7	6	158	132
1988	211	191	4,0	4,6	173	118
1989	227	206	3,8	4,9	142	116
1990	222	199	3,3	3,8	139	113
1991	195	183	4,3	4,8	178	132
1992	176	177	5,7	5,0	165	134
1993	186	175	5,0	5,6	158	118
1994	204	183	4,4	6,0	164	138
1995	206	191	4,1	4,6	143	115
1996	226	214	4,4	5,6	171	142
1997	199	190	3,6	4,3	189	159
1998	215	200	3,5	3,8	175	149
1999	219	202	3,3	3,6	153	136
2000	245	220	3,5	3,8	173	147
2001	225	202	3,5	4,5	182	143
2002	238	202	2,5	3,5		
2003	238	222	2,5	3,3	145	118
2004	223	201	3,4	4,2	165	136
2005	243	219	2,7	4,1	124	112
2006	249	228	3,1	4,9	136	124
2007	211	213	3,4	4,2	159	116
2008	222	203	4,2	4,7	167	124
2009	253	216	3,1	3,8	148	132
2010	242	225	3,0	3,6	125	108
2011						
2012	249	226	2,4	3,5	113	130
2013	219	215	3,4	4,0	118	119
2014	229	223	4,1	5,0	184	142
2015	264	247	3,0	3,7	147	124
2016	246	223	3,0	3,2	152	119
2017	228	217	2,7	3,7	143	131
2018	233	230	2,5	2,8	143	126
2019	244	230	2,7	3,3	127	105
2020	230	235	2,6	3,4	151	99
2021	205	204	3,3	4,0	176	138
2022	241	232	4	3	122	95

Source: Institut des Sciences de la Vigne et du Vin de l'Université de Bordeaux (Baugier, 2023)

3.3. Results and discussions

3.3.1. Key findings

The findings from this study, which covered the period from 1997 until 2022, have corroborated with previous studies and assessments for Bordeaux and other regions outside France.

The conclusion is that climate change has had a positive effect on the quality of wine in the Bordeaux region. Two of the three bioclimatic indices surveyed (Huglin and GST) indicated that the Bordeaux region had entered the optimal zone in terms of wine production quality in the late 1980s. However, these indices differ from the current and future situation. Based on GST, Bordeaux is still in the optimal zone and is expected to continue being so into the mid-2030s. The Huglin index indicates that this range for the Bordeaux region was exceeded in the 2010s, but it is still classified as temperate – warm. As for the grape composition, the substantial increase in the sugar content and the reduction in acidity do not compromise the quality and typicality of the Bordeaux wines. In addition to the ranking analysis, elaborated by Baciocco et al. (2014, p.) until 2009, "The 2021 vintage in Bordeaux" report by the *Université de Bordeaux* confirmed the optimal zone period in the region in the following decade: "*... Already success, the decade from 2010 to 2020 majestically drew to a close with a series of 2018, 2019 and 2020 vintages that boast distinctive styles yet are all equally astonishing*."

To sum it up, Bordeaux wine upholds its reputation in terms of typicity, quality, excellence and uniqueness, which has delighted the world for centuries, despite the evidence of the climate change. In other words, the market for premium wines from Bordeaux continues to have a healthy market share throughout the world. Nonetheless, it is important to follow and monitor the bioclimatic indices in order to make the necessary mitigations, adaptive measures, and suitable usage of the appropriated technology and multidisciplinary approach for all wine industry segments concerned.

3.3.2. Bioclimatic indices

The bioclimatic indices estimation based on historical data from Meteoblue for the 1977-2022 period are: Huglin index (HI), growing season temperature (GST), cool night index (CI) and prior to harvest cool night index (PHCI).

3.3.2.1. The Huglin index

The Huglin index has been estimated for three sites (Listrac Medoc, Pessac and Saint Emilion) in the Bordeaux region using historic weather data provided by Meteoblue AG from January 1977 to December 2022. The index has been calculated annually, based on the growing season period, from April to September. The results regarding the three locations are shown in Table 11 and the trend for the Listrac Medoc is shown in Figure 15. A linear model was calculated producing a mean trend for the period from 1977 to 2022 ($p<0.0001$ and $R^2=0.461$). The graphics and trends for Saint Emilion and Pessac are similar, with a slight change in the correlations, ($p<.0001$ and $R^2=0.499$) and ($p<.0001$ and $R^2=0.487$), respectively. 3

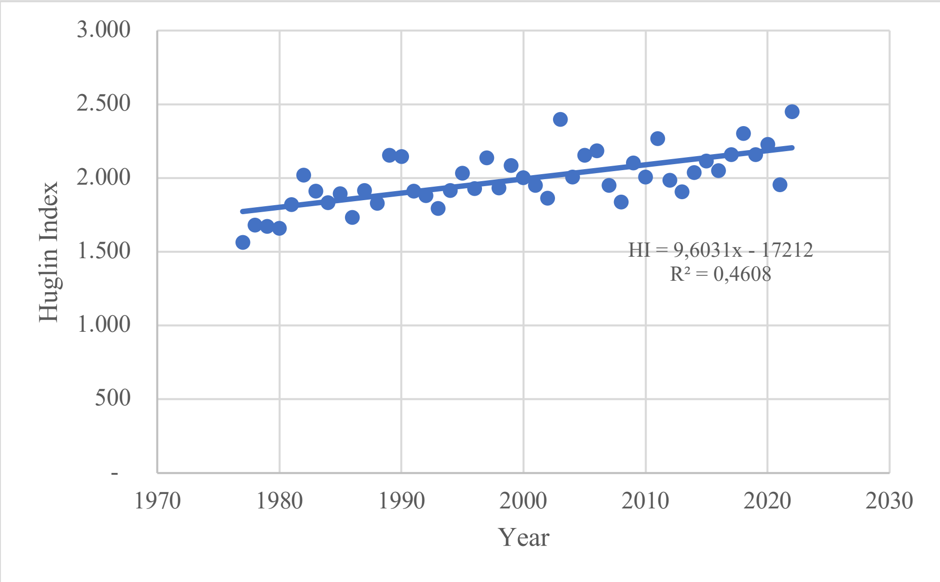

Figure 15. Huglin index for Listrac Medoc from 1977 to 2022

Table 11. Huglin index for three locations in the Bordeaux region for the 1977-2022 period

Huglin Index			
Year	**Listrac Medoc**	**Saint Emilion**	**Pessac**
1977	1.565	1.579	1.619
1978	1.683	1.689	1.765
1979	1.671	1.659	1.739
1980	1.660	1.674	1.730
1981	1.818	1.822	1.902
1982	2.020	2.019	2.106
1983	1.913	1.930	1.962
1984	1.834	1.821	1.905
1985	1.892	1.941	1.976
1986	1.733	1.783	1.817
1987	1.916	1.919	1.990
1988	1.829	1.853	1.906
1989	2.153	2.152	2.216
1990	2.144	2.143	2.207
1991	1.911	1.927	1.988
1992	1.878	1.895	1.936
1993	1.794	1.818	1.866
1994	1.917	1.931	1.991
1995	2.030	2.029	2.131
1996	1.926	1.945	2.014
1997	2.136	2.142	2.217
1998	1.931	1.971	2.019
1999	2.085	2.103	2.159
2000	2.001	2.011	2.089
2001	1.951	1.956	2.037
2002	1.862	1.875	1.951
2003	2.399	2.416	2.493

2004	2.007	2.019	2.092
2005	2.153	2.168	2.252
2006	2.186	2.195	2.262
2007	1.949	1.982	2.026
2008	1.838	1.874	1.925
2009	2.101	2.135	2.209
2010	2.007	2.028	2.123
2011	2.266	2.297	2.383
2012	1.985	2.018	2.095
2013	1.905	1.946	1.985
2014	2.038	2.041	2.134
2015	2.114	2.174	2.232
2016	2.051	2.082	2.144
2017	2.156	2.175	2.220
2018	2.302	2.329	2.362
2019	2.160	2.179	2.251
2020	2.230	2.277	2.318
2021	1.952	1.969	2.032
2022	2.448	2.472	2.531

Throughout the Table 12, it can be noticed that the Huglin index has been rising continuously in the last decades within the 3 Bordeaux regions. The percentages of the escalation are quite similar among the three regions. Comparing the 2010s to the 1980s, the percentage increase is in the range from 11.7% to 12.8%, which is a significant upsurge for the index in question. According to the Huglin classification, the wine-growing climate in Bordeaux region has changed from temperate to warm temperate (> 2100 ≤ 2400) in the 2010s (CIVB, 2023) and (Huglin, 1978).

According to Huglin, the optimal range for producing fine wines such as Merlot and Cabernet Sauvignon varieties is 1900 ≤ H < 2000. Considering the figures of the 1980s, the average Huglin's index for Bordeaux lies at the lower end, 1900, of the optimal zone. In the 1990s, the average index is within the optimal zone. In the 2000s, it was around the upper limits. In the 2010s, the average Huglin index reached the value of 2100s, above the recommended value for Merlot and Cabernet Sauvignon varieties, but still in the warm temperate zone.

Table 12. Variation of the Huglin index over the 1980s, 1990s, 2000s and 2010s

	LISTRAC MEDOC			
	1980 - 1989	**1990 – 1999**	**2000 - 2009**	**2010 -2019**
	1660	2.144	2.001	2.007
	1818	1.911	1.951	2.266
	2020	1.878	1.862	1.985
	1913	1.794	2.399	1.905
	1834	1.917	2.007	2.038
	1892	2.030	2.153	2.114
	1733	1.926	2.186	2.051
	1916	2.136	1.949	2.156
	1829	1.931	1.838	2.302
	2153	2.085	2.101	2.160
AVG	**1863**	**1929**	**2004**	**2082**
SD	**139**	117	169	125
∆ (%) (decade 80)		**3,5%**	**7,5%**	**11,8%**

	SAINT EMILION			
	1980 - 1989	**1990 – 1999**	**2000 - 2009**	**2010 -2019**
	1674	2.143	2.011	2.028
	1822	1.927	1.956	2.297
	2019	1.895	1.875	2.018
	1930	1.818	2.416	1.946
	1821	1.931	2.019	2.041
	1941	2.029	2.168	2.174
	1783	1.945	2.195	2.082
	1919	2.142	1.982	2.175
	1853	1.971	1.874	2.329
	2152	2.103	2.135	2.179
AVG	**1906**	**1958**	**2015**	**2128**
SD	2216	110	167	125
∆ (%) (decade 80)		**2,8%**	**5,7%**	**11,7%**

	PESSAC			
	1980 - 1989	**1990 – 1999**	**2000 - 2009**	**2010 -2019**
	1730	2207	2.089	2.123
	1902	1988	2.037	2.383
	2106	1936	1.951	2.095
	1962	1866	2.493	1.985
	1905	1991	2.092	2.134
	1976	2131	2.252	2.232
	1817	2014	2.262	2.144
	1990	2217	2.026	2.220
	1906	2019	1.925	2.362
	2216	2159	2.209	2.251
AVG	**1934**	**2016**	**2090**	**2182**
SD	137	119	172	122
∆ (%) (decade 80)		**4,3%**	**8,1%**	**12,8%**

Using the formula for simple linear regression, (HI = 9,6936x – 17374; R^2 = 0,461) for Listrac Medoc and the corresponding equations for Saint Emilion and Pessac, extrapolations were made to verify the values of the Huglin Index for the upcoming decades in case such trend continues. For comparison purposes, the average Huglin index for the last ten years was also calculated. The Table 13 shows the results. If the trend of the linear correlation remains the same in the coming years, the classification of the climate class in Bordeaux will move from warm temperate to warm (> 2400 ≤ 3000) in the 2040s.

Table 13. Extrapolation of the linear correlation for the Huglin Index in the Bordeaux region for the coming decades.

Year	HUGLIN		
	Listrac	Saint Emilion	Pessac
2013 -2022	2136	2164	2221
2030	2282	2317	2381
2040	2378	2482	2482
2050	2474	2520	2584

3.3.2.2. Growing Season Temperature (GST)

Figure 16 shows the GST profile for Listrac Medoc. The linear model calculated the mean trend for the period from 1977 to 2022 ($p<0.0001$ and $R^2=0.428$). According to the linear model, the GST in 1977 was 16.6°C and in 2022, 18.4 °C. It means an increase of around 1.8°C over a period of 45 years. According to the GST classification criteria, Bordeaux has moved from an intermediate to warm class within this century (Table 8), which is in line with the Huglin criteria. Saint Emilion and Pessac follow similar pattern.

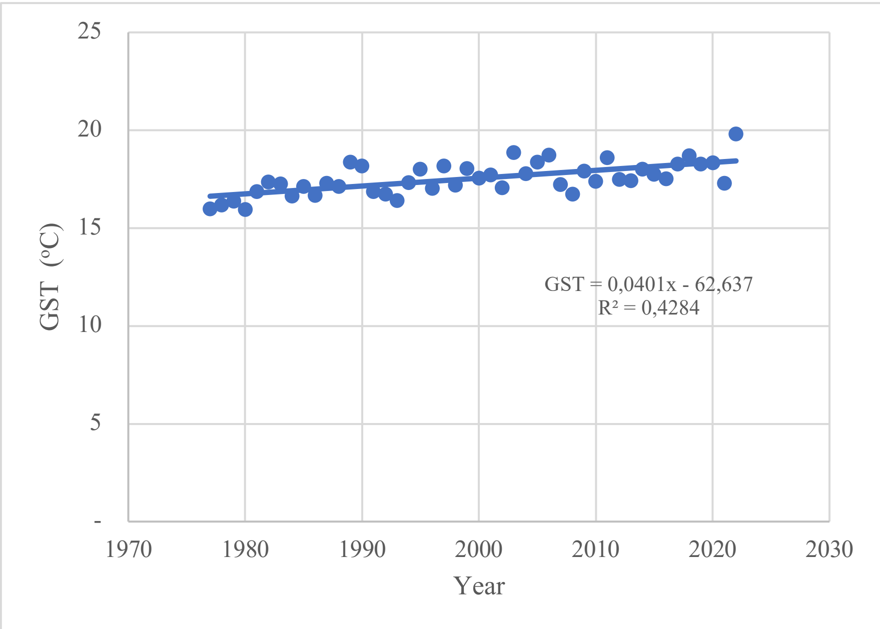

Figure 16. Growing season temperature (GST) for Listrac Medoc in the period of 1977 to 2022

Table 14 shows that Saint Emilion and Pessac follow similar patterns. Huglin index and GST for the three sites have a higher correlation ($p<0.001$ and $R^2= 0.935$) for Listrac

Medoc, ($p<0.001$ and $R^2= 0.934$) for Saint Emilion and for Pessac ($p<0.001$ and $R^2= 0.933$).

According to (Jones, G., 2005), Cabernet Sauvignon and Merlot grow well and reach their optimum, at an average temperature between 17-19°C. Considering the figures in the Table 14, the current average GST for the Bordeaux region is in the optimum zone and will continue considering the extrapolation in a near future. Keeping up with the trend, GST will reach the range of 19-21°C by the end of the 2030s, and it will be classified as a hot climate. Table 14 shows that Saint Emilion and Pessac follow similar patterns.

Table 14. Extrapolation of the growing season temperatures (GST) for Listrac Medoc, Saint Emilion and Pessac

Year	GST		
	Listrac Medoc	Saint Emilion	Pessac
1977	16.64	16.55	16.73
2022	18.45	18.45	18.63
2030	18.77	18.78	18.96
2040	19.17	19.21	19.39
2050	19.57	19.63	19.81

3.3.2.3. Cool night index (CI) and Prior to harvest cool night index (PHCI)

The prior to harvest cool night (PHCI) and cool night (CI) indices were computed according to Comte et al. (2022) and Tonietto & Carbonneau (2004).

PHCI was estimated based on approximately 30 days prior to harvest, as suggested by (Comte et al., 2022) and the CI, for the month of September, as traditionally calculated. Estimation from 1977 to 2022 did not indicate higerh correlations, neither for CI nor for PHCI. Considering only the last decade, Figure 17 shows that mean average trend for PHCI has increased significantly, but for the CI, it seems to be lower than PCHI, however, without a clear trend.

This is because the harvests that were carried out in October were anticipated with some frequency, in comparison to the month of September. It is in line with the results presented by Comte et al. (2022) within the vineyards along the edge of the Lake Neuchatel in Switzerland.

According to (Kliewer, 1972), the effective minimum temperature values, just before harvest, are determinant for wines' aroma and colour.

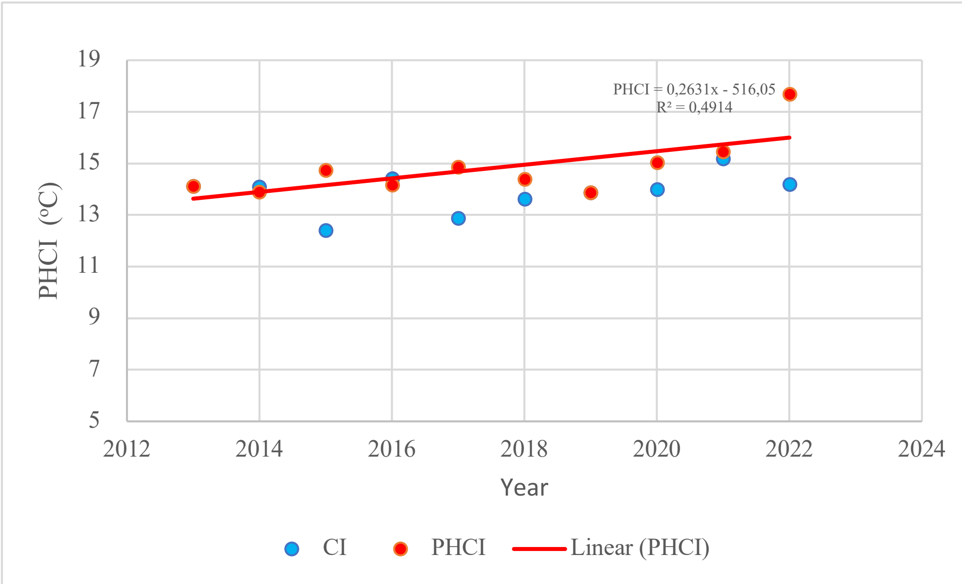

Figure 17. Prior to harvest cool night index - PHCI and CI for Listrac Medoc

3.3.3. Grapevine physiology and biochemistry

For the analysis of the Merlot and Cabernet Sauvignon grape proprieties, data from *Université de Bordeaux* from 1977 to 2022 were computed. The parameters used in the study were sugar content, total acidity, and berry weight.

3.3.3.1. Sugar content

Figure 18 shows a significant and continuous increase in sugar content in the Merlot and Cabernet Sauvignon varieties from the Bordeaux region between 1977 and 2022. The linear correlations are ($p<0,001$ and $R^2=0.473$) for Merlot and ($p<0,001$ and $R^2=0.663$) for the Cabernet Sauvignon. The sugar content of Merlot is higher than Cabernet Sauvignon.

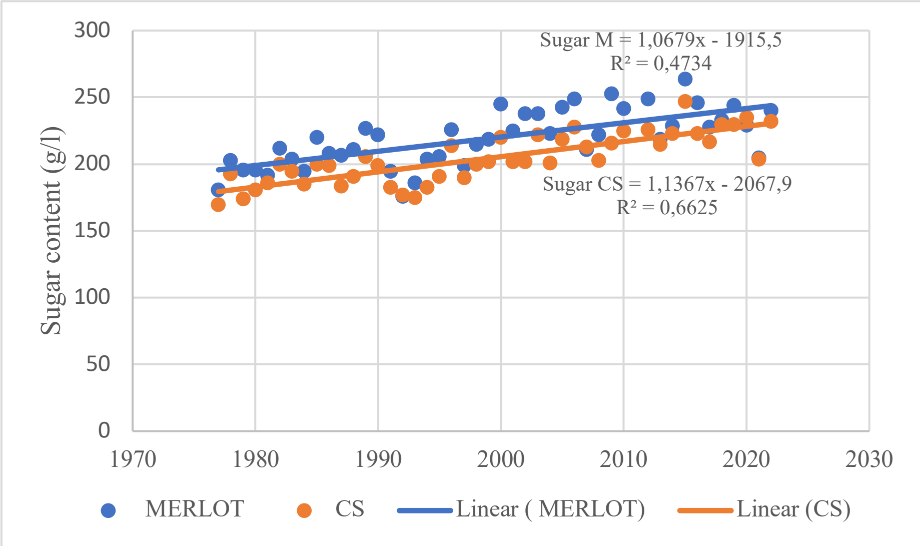

Figure 18. Sugar content for Merlot and Cabernet Sauvignon for the Bordeaux region from 1977 to 2022.

The study (Navrátilová et al., 2020) proved a high correlation between the Huglin index and the sugar content for a period of twenty years in the two wine-growing regions in the Chez Republic-Moravia and Bohemia. The same procedure has been adopted for the Bordeaux region regarding the Huglin index and the GST.

The sugar content of both grapes, Merlot and Cabernet Sauvignon, has showed similar trends of the study mentioned above. The linear correlations are ($p<0,001$ and $R^2=0.454$) for Merlot and ($p<0,001$ and $R^2=0.564$) for Cabernet Sauvignon.

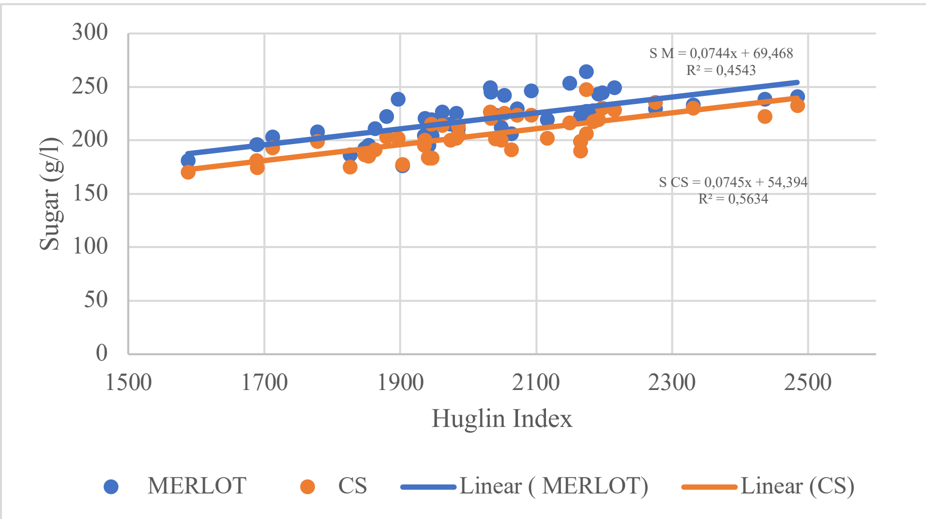

Figure 19. Relationship between Huglin Index and the sugar content of the Merlot and Cabernet Sauvignon grape varieties in the Bordeaux region.

The relationship between GST and the sugar content was also evaluated. As expected, like the Huglin Index, there are good correlations between them, as showed in the Figure

20, ($p<0,001$ and $R^2=0.415$) for Merlot and ($p<0,001$ and $R^2=0.485$) for Cabernet Sauvignon. GST of the graphic below refers to Listrac Medoc. Saint Emilion and Pessac have similar profile and behaviour since the GST regarding them differs quite slightly.

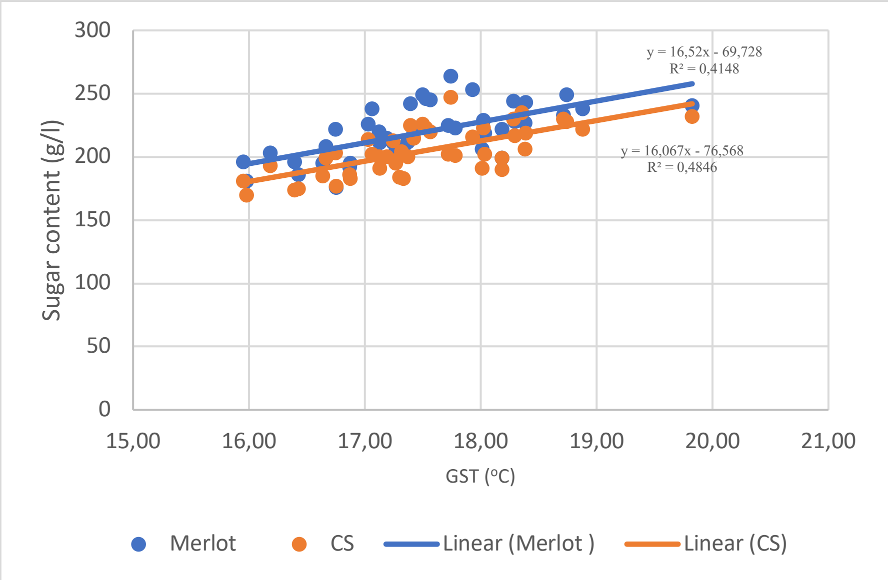

Figure 20. Relationship between GST and the sugar content of the Merlot and Cabernet Sauvignon grape varieties in Listrac Medoc

3.3.3.2. Total acidity

The same evaluation performed for sugar content was repeated on total acidity. As expected, the total acidity goes to the opposite trend of the sugar content. Correlations of total acidity with Huglin Index and GST are in the same magnitude as sugar content.

Figure 21 shows the reduction in total acidity over the years for Merlot and Cabernet Sauvignon grape varieties. The linear correlations are ($p<0,001$ and $R^2=0.614$) for Merlot and ($p<0,001$ and $R^2=0.577$) for Cabernet Sauvignon. The total acidity of Cabernet Sauvignon is higher than Merlot.

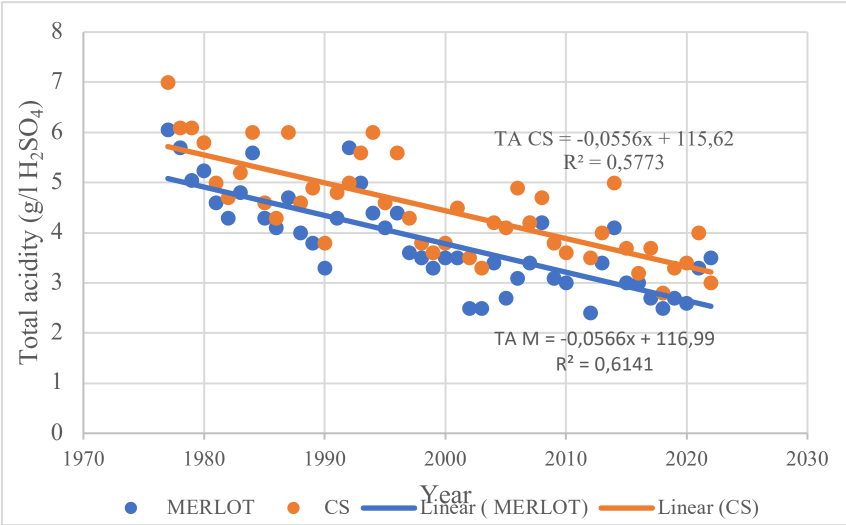

Figure 21. Total acidity of Merlot and Cabernet Sauvignon for the Bordeaux region from 1977 to 2022

Figure 22 shows the relationship between Huglin Index and total acidity of the Merlot and Cabernet Sauvignon grape varieties in the Bordeaux region from 1977 to 2022. The linear correlations are ($p<0,001$ and $R^2=0.519$) for Merlot and ($p<0,001$ and $R^2=0.443$) for Cabernet Sauvignon.

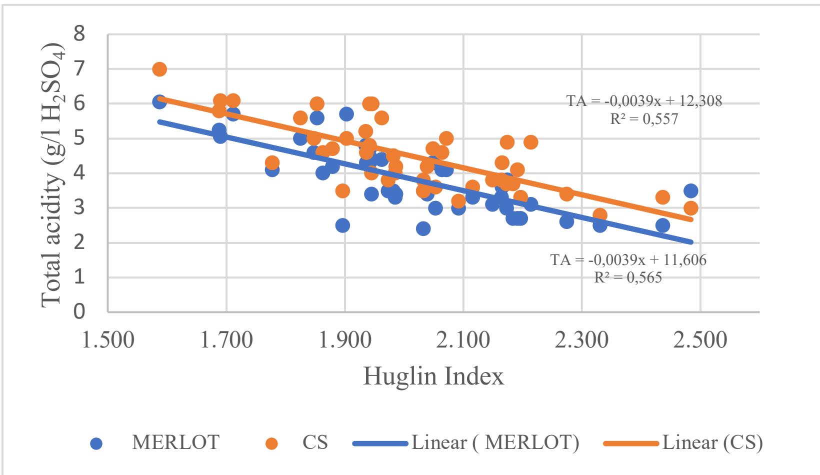

Figure 22. Relationship between Huglin Index and total acidity of the Merlot and Cabernet Sauvignon grape varieties in the Bordeaux region

The correlation between the GST and the total acidity was also examined. Correlations and trends are similar to those for the sugar content, as shown in Figure 23.

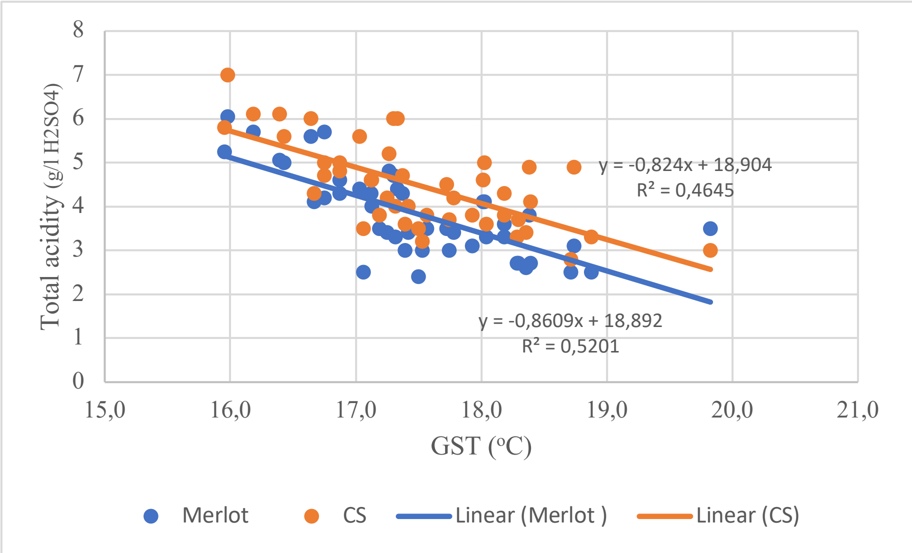

Figure 23. Relationship between GST and acidity of the Merlot and Cabernet Sauvignon grape varieties in Listrac Medoc

The sugar / total acidity ratio has been extensively explored in the literature, but it could be an important source of information in the pre-harvest phase. Jones & Davis (2000) mentioned this index but did not use it for further analysis.

Figure 24 shows the profile of the sugar/total acidity ratio for the grapes Merlot and Cabernet Sauvignon for Bordeaux region from 1977 to 2022.

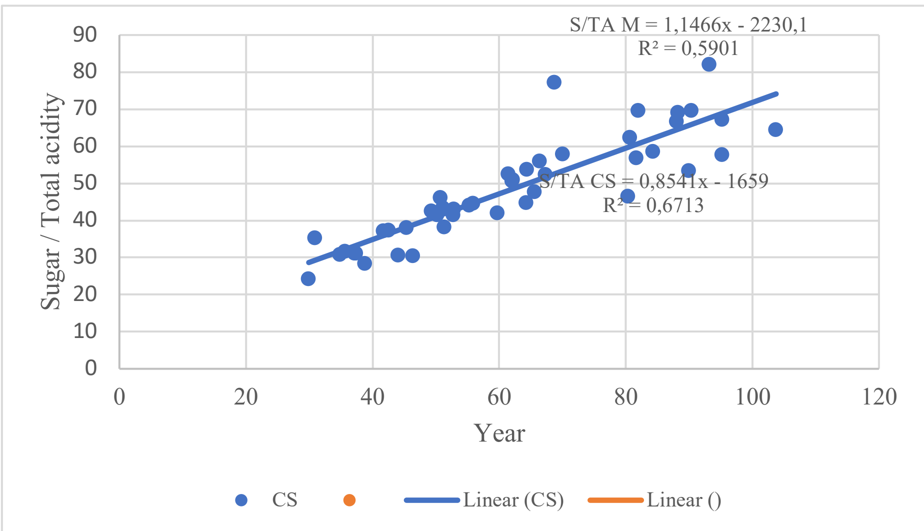

Figure 24. Sugar/total acidity ratio for grapes Merlot and Cabernet Sauvignon for Bordeaux region from 1977 to 2022

The ratio sugar/total acidity for both grape varieties also has high correlations with the Huglin Index and GST, as shown in the Figures 25 and 26.

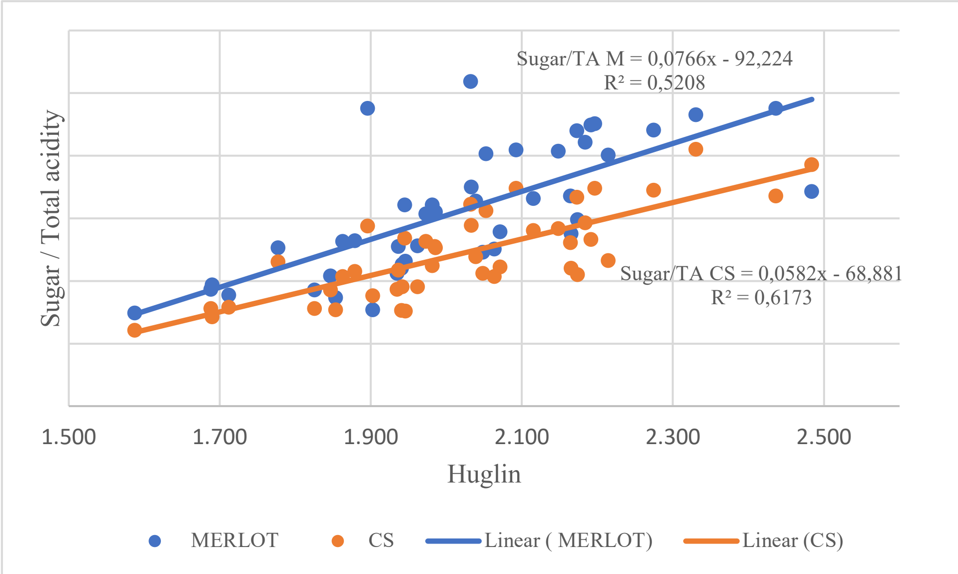

Figure 25. Relationship between the Huglin index and Sugar/total acidity for Merlot and Cabernet Sauvignon from 1977 to 2022

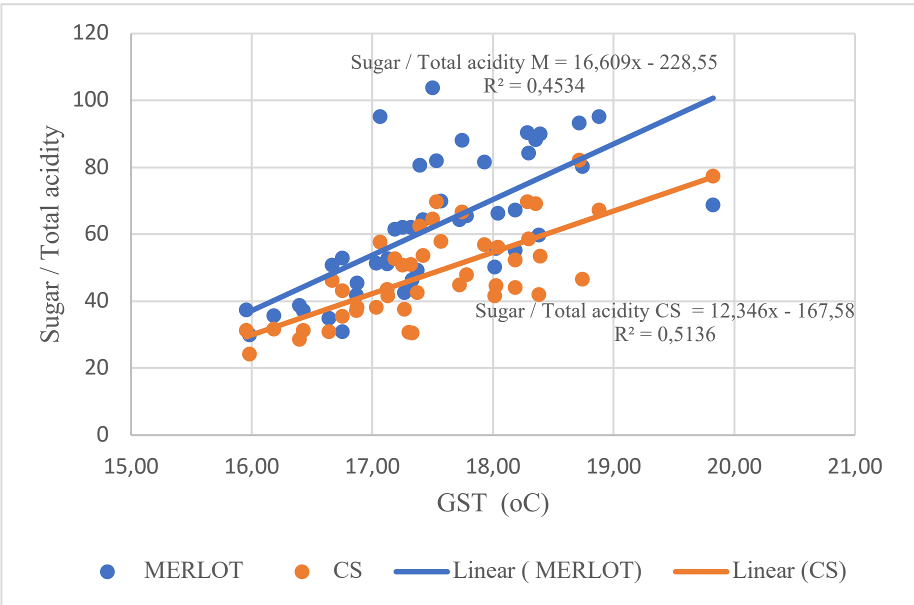

Figure 26. Relationship between the GST and Sugar/total acidity for Merlot and Cabernet Sauvignon from 1977 to 2022

3.3.3.3. Berry weights

Another parameter that the *Université de Bordeaux* has also registered, since 1977, is the weight of the grapes (g/100 units). The correlations for the weight of both grape varieties are very low for the period between 1977 and 2022, as shown in Figure 27.

Just for the comparison with the study performed by Jones & Davis (2000), the correlation for the 1977-1999 period was calculated. In this case, there is a good correlation, for both grapes ($p<0.0001$ and $R^2=0.472$) for Merlot and ($p<0.0001$ and $R^2=0.497$) for Cabernet

Sauvignon and it is in line with the study conducted by Jones & Davis (2000).The correlations had kept the same magnitude until mid-2000s, Figure 28. After 2005, the correlation has fallen, however, there is no relationship between berry weight and the bioclimatic indices, Huglin and GST, for the 2005-2002 period.

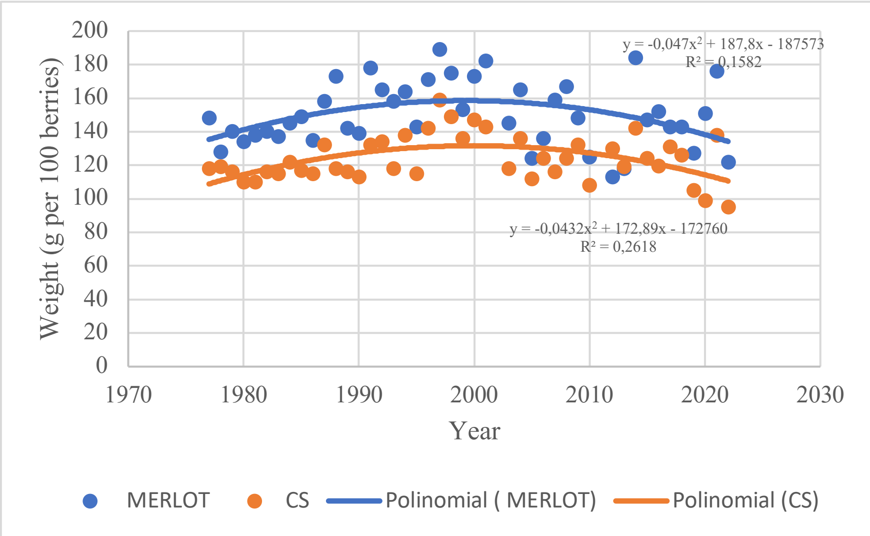

Figure 27. Evolution of the Weight of Merlot and Cabernet Sauvignon from 1977 to 2022 in the Bordeaux region

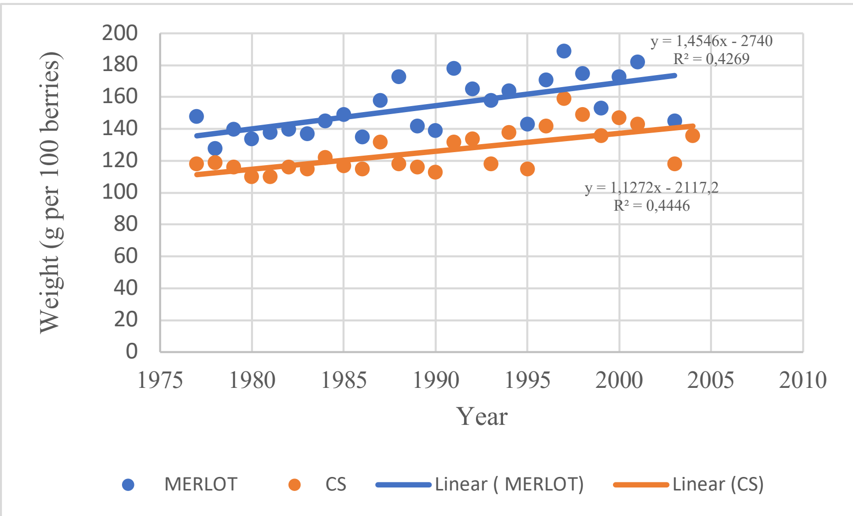

Figure 28. Evolution of the Weight of Merlot and Cabernet Sauvignon from 1977 to 2022 in the Bordeaux region

3.3.4. Wine economics and ranking

3.3.4.1. Bioclimatic indices and ranking

After a deep assessment on the bioclimatic indices, (Huglin, GST and PHCI) it is important to verify how they relate to the wine economics and quality ranking of the Bordeaux wines.

The study carried out by Baciocco et al. (2014) in the Bordeaux region regarding the wine quality Vs climate will be the main source to apply the current bioclimatic indices. The prices of the wines were sourced from the Wine-Searcher website (Wine-Searcher, 2023). It is the biggest wine and spirits search engine with an online magazine. The ranking of the vintage quality based on eight different sources, calculated by the Consensus Ranking (Borges et al., 2012) cover the period from 1961 to 2009. Baciocco et al. (2014) calculated the Top 10 and the Bottom 10 vintages for this period. Although the assessment covers both red and white wines, this study focus on red wines only, since the *Université of Bordeaux* does not provide data for white wines.

Since the data from the *Université of Bordeaux* covers the period beginning with 1977, a new ranking had been developed for the Top 10 and Bottom 10. The ranking is presented in order from the best to worst in Table 15.

The annual values of the respective Huglin indices have been classified for the Top 10 and Bottom 10 vintages. It can be observed that the highest Huglin indexes are located at the Top 10. Eight Huglin index out of Top 10 have values above the average (1967) along with 33 vintages analysed. The average Huglin index for the Top 10 is 2097. As for the Bottom 10, it is the opposite, eight out 10 are located below the average of Huglin index for the same period. The average Huglin index for the Bottom 10 is 1892. It is important to stress that the vine culture optimal conditions suggested by Huglin for Cabernet Sauvignon and Merlot has been $1900 \leq H < 2000$, i.e., despite the optimal range suggested by Huglin ($1900 \leq H < 2000$), the average index for the TOP 10 is a little higher. As for the Bottom 10, the average index is slightly below. The Huglin index, considering an average of the three sites, reached the optimal zone for Cabernet Sauvignon and Merlot by the end of 1980s, according to the linear regression. ($HI = 9{,}9614x – 17895$, $R^2 = 0{,}4833$).

The growing season average temperature, GST, for the TOP 10 is 17.9ºC and for the BOTTOM 10 is 16.8ºC. The number of vintages in the Top 10 with GST above the average for the period, 1977 – 2009, (17.35 g/l) is 6. For the Bottom 10, only one vintage is above the average. The temperature of 17.9ºC is classified as warm climate and the temperature of 16.8ºC is classified as intermediate climate, according to (Jones et al., 2005). Cabernet Sauvignon and Merlot grow well and have their optimum, at GST between 17 – 19ºC. The linear correlation for GST, (GST = 0,0415x - 65,34; R^2= 0.446) shows that it (average of Listrac Medoc, Saint Emilion and Pessac) have also reached the optimum range for Merlot and Cabernet Sauvignon by the end of the 1980s and will continue doing so until the mid of 2030s.

The average sugar content of Cabernet Sauvignon in the Top 10 is 207 g/l and in the Bottom 10 is 184 g/l. The average sugar concentration for the period from 1997 to 2009 is 197 g/l. Therefore, 9 out of 10 of the Top 10 vintages are above the average and only 1 from the Bottom 10 is above the average.

The same analysis conducted for the total acidity for Cabernet Sauvignon shows that 9 out of 10 vintages for the Top 10 are below the average total acidity (4.8 g/l) and 7 are above for Bottom 10.

For the ratio "Sugar/total acidity", and the same grape variety, Cabernet Sauvignon, 7 out of 10 vintages of the Top 10 are above the average (42.86) and only 2 vintages from the Bottom 10 are above the average. The same evaluation was applied to the Merlot variety and the results were quite similar.

Table 15 shows a summary for the two grape varieties.

Table 15. Classification of Huglin index, GS, sugar content , total acidity and sugar/total acidity ratio and Bordeaux wine ranking

	HUGLIN		GST (ºC)		SUGAR (g/l)		TA (g/l H2SO4)		Sugar / TA	
YEAR	**TOP 10**	**BOTTOM 10**			**TOP 10**	**BOTTOM 10**	**TOP 10**	**BOTTOM 10**	**TOP 10**	**BOTTOM 10**
2009	2149		18,05		216		3,8		56,8	
2000	2033		17,58		220		3,8		57,9	
1982	2048		17,41		200		4,7		42,6	
2005	2192		18,45		219		4,1		53,4	
1990	2165		18,19		199		3,8		52,4	
1989	2174		18,38		206		4,9		42,00	
1995	2063		18,07		191		4,6		41,5	
1986	1778		16,75		199		4,3		46,3	
1985	1936		17,23		200		4,6		43,5	
2003	2436		18,92		222		3,3		67,3	
1977		1603,0		15,99		170		7,0		24,3
1984		1871,0		16,63		185		6,0		30,8
1991		1961,0		16,90		183		4,8		38,1
1980		1704,0		15,98		181		5,8		31,2
1992		1921,0		16,75		177		5,0		35,4
1987		1960,0		17,34		184		6,0		30,7
1993		1843,0		16,47		175		5,6		31,3
1997		2186,0		18,21		190		4,3		44,2
1981		1865,0		16,88		186		5,0		37,2
2007		2005,0		17,30		213		4,2		50,7
AVG	**2097**	**1892**	**17,90**	**16,85**	**207**	**184**	**4,2**	**5,4**	**50,4**	**35,4**

Table 16. Classification of the grape parameters in the ranking of wine quality in Bordeaux region from 1977 to 2009

	MERLOT		CABERNET SAUVIGNON	
	Top 10	Bottom 10	Top 10	Bottom 10
Sugar (g/l)	7	0	9	1
Total acidity (g/l H2SO4)	8	2	9	1
Sugar / Total acidity	6	0	7	2

3.3.4.2. Market price

The analyses above confirmed that the bioclimatic indices have a significant correlation with the quality and ranking of the Bordeaux wines. Next step is to evaluate the relationship between the Top 10 and Bottom 10 and their prices provided by Wine-Searcher (Wine-Searcher, 2023).

Figure 29. shows the average price of the Top 10 and Bottom 10 from 1977 to 2009 of the 5 Premier Crus from Bordeaux: Chateau Haut-Brion, Chateau Lafite-Rothschild, Chateau Latour, Chateau Margaux, and Chateau Mouton Rothschild. Appendix 1 shows their detailed prices for the 1977-2021 period.

This study has concluded that the Huglin and GST bioclimatic indices reached the optimal zone for the production of fine wines in Bordeaux by the end of the 1980s. Figure 29 shows that 7 out of the Top 10 analysed throughout this period, are produced within the most optimal period: the end of 1980s and 2009, thus, the highest price.

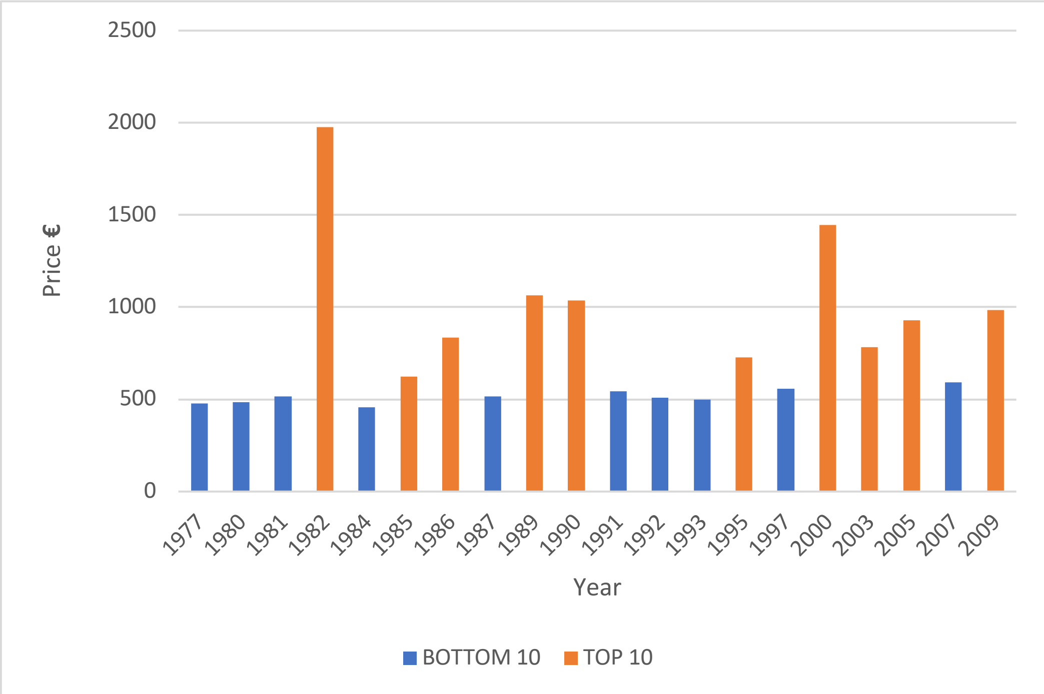

Figure 29. Average wine prices of the Top 10 and Bottom 10 of the 5 Premier Cru of Bordeaux within the 1997-2009 period

Table 17 shows that the difference of the average price of the Top 10 and Bottom 10 of 5 Premier Crus from Bordeaux is the magnitude of 100%, i.e., double the price.

It can be deduced that the properties of Merlot and Cabernet Sauvignon grapes have positive effects in terms of quality and price for the wine in the Bordeaux region, due to the climate change.

Table 17. Price difference of the Top 10 and Bottom for the 5 Premier Cru of Bordeaux within the 1997-2009 period

YEAR	Haut-Brion	Latour	Mouton R.	Lafite	Margaux
	TOP 10				
2009	864	1.277	804	1.068	905
2000	945	1.198	2.315	1.626	1.148
1982	923	2.199	1.828	3.901	1.038
2005	911	975	790	1.063	908
1990	1.077	995	579	1.195	1.342
1989	2.493	628	634	939	631
1995	610	721	633	1.014	654
1986	503	690	1.024	1.228	732
1985	555	536	522	857	639
2003	552	941	624	1.086	707

AVG	**€ 943**	**€ 1.016**	**€ 975**	**€ 1.398**	**€ 870**
	BOTTOM 10				
1977	391	542	574	560	329
1984	325	445	450	639	423
1991	477	542	491	706	502
1980	402	485	485	675	366
1992	411	482	481	694	474
1987	408	425	529	753	460
1993	416	499	506	614	463
1997	507	542	528	679	536
1981	428	458	401	812	477
2007	474	613	542	835	499
AVG	**€ 424**	**€ 503**	**€ 499**	**€ 697**	**€ 453**
∆ Top 10/Bottom 10	**123%**	**102%**	**96%**	**101%**	**92%**

4. Conclusions

The aim of this study was to verify how the Climate Changes have impacted the quality of wine in the Bordeaux region. In other words, if Bordeaux could remain at the wine industry forefront, in terms of quality and marketability, despite the changes brought by the shifting climate. For that, bioclimatic indices, well-known and widely explored in the scientific segment, were utilized. Winegrape physiology data were used to verify the correlation between these indices. For the wine economics, market price and ranking of the vintages were also employed.

Several studies have concluded that until the end of the last century and the beginning of this one, Climate Change has had an overall positive impact on the quality of Bordeaux wines.

4.1. Summary of the results

The Huglin Index, a reference in bioclimatic indices, mainly after the advent of the Climate Change, indicated that the wine growing climate has changed from temperate to warm temperate in the Bordeaux region. The computed regression indicated that the Huglin Index has substantially increased in the observed period of the last forty-five years. The average Huglin Index for the 2010s had increased by around 11.8% compared to the average of the 1980s, for Medoc Listrac, 11.7% for Saint Emilion and 12.8% for Pessac.

The Huglin Index has described the impact of the air temperature on the sugar content for both grapes varieties, Merlot and Cabernet Sauvignon, in a statistically noteworthy trend. The Huglin Index is well suited to demonstrate the relationship between wine growing climate and sugar content.

The same assessment was performed to verify the relationship between the Huglin Index and the total acidity for Merlot and Cabernet Sauvignon. It is also suited to portray the relationship between the wine growing climate and the total acidity.

The growing season average temperature index (GST), one of the most advanced single indices for identifying region climates, has also increased significantly over the observed period. According to the linear model, the GST increased around 1.8ºC over a period of forty-five years, 16.6ºC in 1977 to 18.4 ºC in 2022. According to the GST classification criteria, the Bordeaux region has moved from an intermediate to a warm wine growing climate within this century, which has also been in line with the Huglin criteria. Saint Emilion and Pessac have had similar profiles.

The prior to harvest cool night (PHCI) and cool night (CI) indices has also been made use of. PHCI was estimated based on approximately 30 days before the harvest, and the CI, for the month of September. Estimation from over the 45 years did not indicate higher correlations, neither for CI nor for PHCI. Considering only the last decade, average trend for PHCI has increased significantly, but for the CI, it seems to be lower than PCHI, however, without a well-defined trend.

According to linear regression equation the average sugar content for Merlot and Cabernet were 186 and 179 g/l in 1977, respectively. In 2022, the figures for Merlot and Cabernet Sauvignon were 234 and 231 g/l – a significant increase of 25.9% and 28.5%, respectively. It is well-known that acidity and sugar content have opposite trends when it comes to the temperature increase.

The total acidity has reduced around 50% for Merlot and 44% for Cabernet Sauvignon, for the same period in the percentage terms. The average total acidity for Merlot dropped from 5.1 to 2.5 g/l H_2SO_4 and for Cabernet Sauvignon, from 5.7 to 3.2 g/l H_2SO_4, from 1977 to 2022.

The sugar/total acidity ratio was also computed. As it happens, the ratio has increased significantly over the 45 years. For Merlot, using the linear regression, the estimated average ratio went from 36.7 in 1977 to 88.3 in 2022, an increase of around 140%; whereas for Cabernet Sauvignon, from 29.6 to 68, an increase of 130%.

With the information and conclusions obtained from the deep assessment on the bioclimatic indices, (Huglin, GST and PHCI) and their relationship with the physiology of the grapes (sugar and acidity), it was verified how they relate to the wine economics and the ranking of the vintages of the Bordeaux region.

For this evaluation, the best 10 (Top 10) and the worst 10 (Bottom 10) vintages from 1997 to 2009 in the Bordeaux region were looked at. This classification was carried out by a previous study (Baciocco et al., 2014) and served as the reference for this assessment. The prices of the 5 Premier Crus from Bordeaux were obtained from the Wine-Searcher website (Wine Searcher, 2023).

In the ranking of the Top 10, there were basically the vintages with sugar content above the average for the period from 1977 to 2009. In the case of total acidity, the opposite had occurred. Within the Top 10, the total acidity was, in most cases, below the average. The above the average sugar Vs total acidity ratio had been also prevalent in the Top 10 vintages. And most of the vintages in the Top 10 ranking, from 1977 to 2009, were fashioned just after the Bordeaux region had reached the optimal zone, according to bioclimatic indices, which occurred in the late 1980s. Indeed, the market prices of the Top 10 wines for the 5 Bordeaux Premier Crus were on average, almost double compared to the Bottom 10.

4.2 Interpretation of the findings

The findings from this study, over a period of 45 years, from 1997 until 2022, have confirmed the results and conclusions of the previous studies and assessments for Bordeaux and other regions worldwide. There is a consensus that insofar, the climate change has had a positive effect on the quality of wine in the Bordeaux region. The bioclimatic indices, Huglin and GST, indicate that the Bordeaux region had entered at the optimal zone in terms of wine production quality in the late 1980s and has remained at this position ever since. The Huglin index indicates that this range for Cabernet Sauvignon and Merlot was exceeded, but the climate has been still classified as warm temperate. For GST, Bordeaux is still in the optimal zone, and it is expected to continue so well into the mid of 2030s.

As for the grape composition, the substantial increase in the sugar content and the reduction in acidity did not compromise the balance, the finesse, and the elegance of the Bordeaux wine.

The graphic below, elaborated by Dr. Gregory V. Jones illustrates in a clear way which zone of climate the Bordeaux region is located in. Before the 1980s, although Bordeaux used to produce outstanding wines, it was common for the winemakers to face difficulties with the ripening of the grapes. Probably, before the 1980s, the climate in Bordeaux was positioned at the beginning of the curve of the optimum zone. From the end of 1980s until now, the bioclimate indices indicates the Bordeaux region has been positioned at the top of the curve of the optimum zone. Although this study did not cover mitigation and adaptation issues in the vineyard and production, which could improve the overall quality of the wine, the big concern about the disequilibrium that sugar and acidity could impact the quality of the Bordeaux wine due to the Climate Change has not materialised

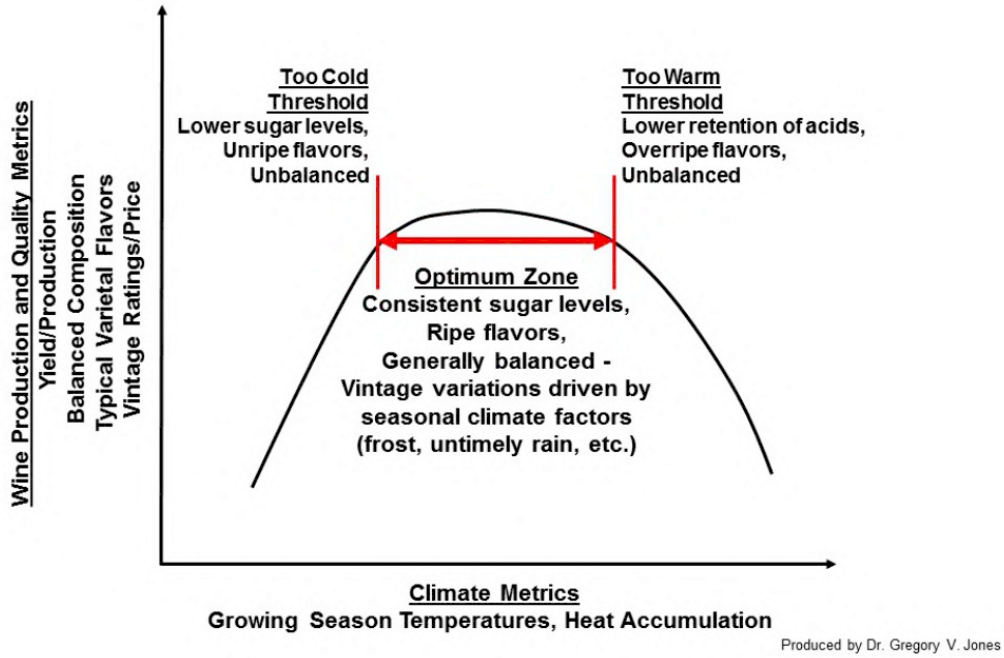

Figure 30. Climate Metrics and Wine Production and Quality Metrics
Source: Jones *& Davis* (2000)

As for the wine economics, the bioclimatic indices and the physiology of the grapes have had a significant correlation between the quality, ranking and pricing of the Bordeaux wines. Strong evidence is in the price difference between the Top10 and Bottom 10, which has been in the magnitude of 100%. And the fact that the Climate Change has moved the climate to the optimum zone of the wine production, it could be perceived as the guarantee that the Bordeaux wine will continue to uphold its position as the top-tier wines.

And yes, Bordeaux can and will remain at the wine industry forefront.

4.3 Limitations and suggestions

It has not been possible to gain the access to additional information of the chateaux which provided the data to the Université of Bordeaux, since its name has been kept confidential. The bioclimatic indices have been very useful to estimate the suitability of certain wine regions for several grapevine varieties and the impacts of the climate change. However, since the Climate Change has become an undeniable reality, many winemakers have undergone through a series of changes when it comes to vineyards and production processes in order to mitigate and adapt themselves to the new challenges and scenarios, something the bioclimatic indices cannot encompass. The information of this sort would be highly useful for a systemic evaluation in this type of study. Even if the bioclimatic indices had not been in the optimum zone, the application of new technologies, mitigation and adaption programmes could have had a positive impact on the overall quality of the wine.

As for suggestions, new surveys on this type of assessment could try to acquire detailed information with CIVB and/or chateaux about the mitigation and adaptation practices of the winemakers in order to face the Climate Change and develop a multidisciplinary and systematic approach to the Bordeaux wine industry. Moreover, the sugar Vs total acidity ratio could be explored even further, acting as a worthy reference for the optimal time of harvest.

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6. Appendix

6.1. Appendix 1: Prices of the Bordeaux Premier Crus from 1977 to 2021

Table 18. Prices of the Bordeaux Premier Crus from 1977 to 2021

Year	Chateau Margaux	Chateau Latour	Chateau Haut Brion	Chateau M. Rothschild	Chateau L. Rothschild	AVG
1977	€ 329	€ 431	€ 395	€ 573	€ 558	€ 454
1978	€ 397	€ 580	€ 487	€ 432	€ 672	€ 562
1979	€ 444	€ 490	€ 497	€ 366	€ 614	€ 532
1980	€ 366	€ 486	€ 405	€ 494	€ 674	€ 521
1981	€ 477	€ 457	€ 440	€ 400	€ 812	€ 600
1982	€ 1.038	€ 2.198	€ 908	€ 1.810	€ 3.954	€ 2.410
1983	€ 703	€ 518	€ 428	€ 440	€ 715	€ 616
1984	€ 423	€ 445	€ 328	€ 445	€ 650	€ 499
1985	€ 639	€ 519	€ 558	€ 515	€ 849	€ 683
1986	€ 732	€ 703	€ 493	€ 989	€ 1.259	€ 889
1987	€ 460	€ 422	€ 407	€ 532	€ 753	€ 559
1988	€ 598	€ 608	€ 501	€ 457	€ 923	€ 711
1989	€ 631	€ 628	€ 2.540	€ 640	€ 934	€ 1.133
1990	€ 1.342	€ 978	€ 1.075	€ 572	€ 1.192	€ 1.156
1991	€ 502	€ 543	€ 477	€ 488	€ 705	€ 586
1992	€ 474	€ 475	€ 417	€ 481	€ 689	€ 549
1993	€ 463	€ 493	€ 412	€ 519	€ 617	€ 520
1994	€ 495	€ 552	€ 456	€ 501	€ 729	€ 592
1995	€ 654	€ 720	€ 610	€ 627	€ 1.021	€ 805
1996	€ 899	€ 832	€ 563	€ 626	€ 1.076	€ 889
1997	€ 536	€ 533	€ 514	€ 521	€ 679	€ 588
1998	€ 562	€ 659	€ 702	€ 686	€ 916	€ 751
1999	€ 619	€ 660	€ 528	€ 581	€ 844	€ 699
2000	€ 1.148	€ 1.197	€ 944	€ 2.319	€ 1.631	€ 1.310
2001	€ 599	€ 654	€ 505	€ 642	€ 929	€ 723
2002	€ 556	€ 590	€ 447	€ 538	€ 799	€ 638
2003	€ 707	€ 941	€ 549	€ 621	€ 1.083	€ 873
2004	€ 536	€ 590	€ 463	€ 570	€ 801	€ 638
2005	€ 908	€ 976	€ 911	€ 793	€ 1.072	€ 988
2006	€ 545	€ 614	€ 503	€ 626	€ 848	€ 672
2007	€ 499	€ 613	€ 475	€ 539	€ 839	€ 653
2008	€ 537	€ 611	€ 487	€ 619	€ 903	€ 688
2009	€ 905	€ 1.275	€ 868	€ 810	€ 1.076	€ 1.040
2010	€ 860	€ 1.364	€ 875	€ 854	€ 1.061	€ 1.044
2011	€ 499	€ 585	€ 493	€ 541	€ 784	€ 629
2012	€ 516	€ 574	€ 470	€ 564	€ 811	€ 636
2013	€ 479	€ 548	€ 432	€ 557	€ 791	€ 608
2014	€ 508	€ 590	€ 470	€ 558	€ 825	€ 644
2015	€ 1.424	€ 708	€ 624	€ 625	€ 847	€ 890
2016	€ 714		€ 642	€ 785	€ 942	€ 810
2017	€ 506		€ 459	€ 536	€ 783	€ 633
2018	€ 716		€ 578	€ 714	€ 931	€ 789
2019	€ 734		€ 563	€ 689	€ 838	€ 743
2020	€ 724		€ 572	€ 690	€ 821	€ 735
2021	€ 545		€ 516	€ 530	€ 639	€ 585
AVG	**€ 556**	**€ 590**	**€ 501**	**€ 570**	**€ 838**	**€ 672**

Source: Wine-Searcher