Ca' Foscari
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Final Thesis

The impact of climate change on the wine business

Risks metrics on selected
Italian production areas

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SUMMARY

ABSTRACT

Wine production is considered the canary in the coal mine of climate change risk. The objective of this thesis is to analyze the possible implications of climate change on the Italian wine sector's profitability.

The thesis firstly discussed the main features of the wine sector that are relevant in the context of climate change. Then, by means of a literature review, it identifies the challenges that prevent carrying out a standard econometric analysis of the impact of climate change on firms' values in the wine business.

Secondly, a qualitative analysis of the credit risk is conducted, identifying the transmissions channels that, starting from climate change-related hazards, may worsen the financial position of wine firms and credit institutions that finance these firms.

In the final part, an empirical risk analysis is conducted on the main viticultural Italian areas, using an agroclimatic indicator (Huglin Index) commonly used in the wine business. This analysis is conducted on two projected emissions scenarios (RCP 2.6 and RCP 6.0), using a dataset covering the period 1951-2099.

CHAPTER 1 - WINE SECTOR: THE CANARY IN THE COAL MINE OF CLIMATE CHANGE RISK

1 Climate change impact on financial investments

The first paragraph of this thesis will be introductive. Then, there will be an explanation of what we consider climate change. Instead, the second section describes how climate changes could impact financial investments and how this topic has become one of the main issues related to global financial stability. In the final paragraph, there is an explanation of the objective of this thesis and the methodology adopted to analyze the wine sector as a case study for climate change-related physical risk.

1.1 Climate change

Climate change can have slightly different definitions. UNFCCC[1] defines it as:

"a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable periods."[2]

While the IPCC[3] refers to:

"a change in the state of the climate that can be identified (e.g., by using statistical tests) by changes in the mean and the variability of its properties and that persists for an extended period, typically decades or longer. Climate change may be due to natural internal processes or external forcings such as modulations of the solar cycles, volcanic eruptions, and persistent anthropogenic changes in the composition of the atmosphere or land use."[4]

[1] United Nations Framework Convention on Climate Change
[2] IPCC (2014) Annex II
[3] Intergovernmental Panel on Climate Change
[4] IPCC (2014) Annex II

The two definitions differ only by the source of climate change. If it is triggered only by human activities or both human activities and natural causes, the first definition is indeed a subset of the second one. The referral to climate and not to weather change is due to the statistical description of the first term. Differences in the definitions of the two terms are that while weather describes a meteorological element of the atmosphere (e.g., temperature, pressure, humidity), climate describes the statistical description of a weather quantity over a range of time in terms of mean and variability. Climates represent surface quantities (e.g., precipitation on the surface, the temperature on the surface) and statistics such as magnitude, persistence, and trends of associated occurrence (e.g., heat waves, drought). In this sense, we can refer to weather change as a short-term condition, while climate change refers to the weather change averaged over a long period and so to a long-term change. Hsiang (2016) gives a statistical definition of the two terms.

In this thesis, when we talk of climate change, we refer to the second definition of climate change between the two described before, which is the one given by the IPCC. There will not be a separation on the sources of climate change since there is a significant focus on impacts. The already cited IPCC stands for Intergovernmental Panel for Climate Change. IPCC is a United Nations body delegated to assess scientific facts related to climate change. It was created to give policymakers an updated and constant assessment of climate change. It gives:

- implications and potential future risks.
- adaptation and mitigation options.

The importance of this body is due to the Assessments Reports (i.e., AR), produced every seven years, approved, and reviewed by all the member states. This approval process assures the high trustworthiness of such a reference. Furthermore, these reports are neutral, and their function is not to be policy-descriptive but only policy-relevant. For these reasons, the IPCC assessment report will be one of the primary references in this thesis.

Furthermore, the IPCC (2014) Assessment Reports is a good starting point to describe the complex topic of climate change briefly. The report observed different facts listed below:

(1) Humans clearly influence the climate, and recent anthropogenic emissions of greenhouse gases are the highest in history. Recent climate changes have had widespread impacts on human and natural systems[5].

(2) The prolonged release of greenhouse gases will cause further warming and durable alterations to climate systems components. These durable alterations will increase the probability of severe, pervasive, and irreversible impacts for ecosystems and humanity. Therefore, limitations of the climate change-related risk require substantial and sustained decreases in GHG and adaptation[6].

(3) Strategies for adaptation and mitigations to climate change need to be complementary to reduce and manage risks related to climate change. In particular: Significant emissions decrease over the following few decades can reduce climate risks; increased prospects of effective adaptation will reduce the costs and challenges of mitigation in the long run[7].

(4) No single option of adaptation or mitigation is sufficient by itself; there is the need for a unified reaction that matches and connects other society goals with adaptation and mitigation objectives[8].

There are observed changes in the climate system. Global warming brings visible consequences, such as sea and atmosphere warming, melting glaciers, and sea-level rise. There are also evident projected changes. For example, it is considered in the notation of IPCC[9], very likely an increase in frequency and magnitude of heatwaves and extreme precipitation events. It is also very likely that ocean acidification and the rise in water temperature combined with the continuous growth of the global mean sea level.
Another aspect that needs to be underlined is the variations across intensity and regions of these projected changes. These variations are expected to increase over time, and this will cause uncertainty problems.

[5] IPCC (2014) SPM 1. Observed Changes and their Causes
[6] IPCC (2014) SPM 2. Future Climate Changes, Risks, and Impacts.
[7] IPCC (2014) SPM 3. Future Pathways for Adaptation, Mitigation and Sustainable Development.
[8] IPCC (2014) SPM 4. Adaptation and Mitigation.
[9] Very likely: 90-100% probability; Likely 66-100% probability; About as likely as not: 33 to 66% probability.

In the last few decades, climate changes have also caused impacts both on natural and human systems on all continents and across the oceans. These observed impacts underlined the sensitivity of natural and human systems to changing climate. There are specific and associated implications for every tiny change and a resulting impact that may cause economic losses. Given the increasing variations described before, future risks and consequences caused by climate change will be even more heterogeneous, and therefore, risks in the future will be unevenly distributed.

Given that there are observed and projected changes in the climate system and associated observed impacts for observed climatic changes, it is also helpful to understand the projected effects of climate change. The main projected impacts are:

- Reduced renewable fresh surface water and groundwater.
- Irreversible regional-scale changes in ecosystems, including mass extinctions.
- Sea level rise with consequential submersion, coastal flood, and erosion.
- Important negative implications for food security, increased displacement of people, and consequent increase in conflicts.

It is straightforward to affirm that the effect on the economy and financial stability is detrimental with every projected impact listed above. However, the economic impacts of climate change are difficult to estimate, and there is an uprising need for metrics and methodologies that could assess these risks. In the next paragraph, these topics will be deepened by analyzing the financial perspective of this particular risk.

1.2 Climate-related financial risk

When we talk about climate change, we usually refer to *risks related.* Oxford English Dictionary defines risk as:

"Hazard, a chance of bad consequences, loss or exposure to mischance."

Risk in a financial contest is a term that could have different definitions. It can be associated with volatility (i.e., price return variance); the term refers in this sense also to the possibility of gains and not only to losses. In this thesis, we followed the definition given by the "Quantitative Risk Management" 2005 by A. McNeil, R. Frey, P. Embrechts (ETH Zurich):

"Any event or action that may adversely affect an organization's ability to achieve its objectives and execute its strategies"

It is essential to understand how climate change has become an uprising topic in the financial contest and why climate change implies new sources of financial risk.
This topic associated with finance has developed through the last two decades following the achievement in the comprehension of climate change consequences and the evidence of the impacts.

It is now well known that without an adequate mitigation action, climate change implies an increasing potential economic impact, from adverse to catastrophic, due to extreme weather events and other types of hazards, across several economic activities and geographical areas.
Moreover, mitigation actions through a disorder transition could generate disruption with adverse impacts on different sectors of the economy. Therefore, a mitigation action needs to be done in the following few decades. This mitigation action will require a fast and significant transformation of industrialized and developed economies (e.g., energy sources, production channels, and consumption systems).

These two aspects underlined are the basis of the two groups of financial risks related to climate change. The first is the physical risk, and the second is the transition risk. These two categories are defined in Table 1, present on the following page.

Due to the efficiency of markets, financial markets should process all relevant information and discount them into financial assets values. Moreover, future climate impacts related to physical and transition risk should be already processed with consequent adjustments in the value of investors' financial assets. However, there are problems in the internalizations of the knowledge of climate change in prices and risk metrics.

Physical Risk	*Risk of damages to physical assets, natural capital, and human lives resulting in output losses due to climate-induced weather events.*
Transition Risk	*It occurs in the transition towards a greener economy. During this shift, some sectors of the economy face significant changes in asset values or higher operational costs. The risk arises related to the transition speed and not related to the policies themselves. In this sense, if there is a disorderly transition, the risk increase.*

Table 1: *Definitions of the two types of climate change financial risk. Source: Bank of England (2019)*[10]

Climate changes have consequences both in the financial stability of singular institutions and on the global financial stability, in particular:

(1) Climate risk is relevant for the financial stability of individual institutions. For climate risk, we refer to both the physical effects of climate change and the consequences of a transition to a greener economy for some sectors of the economy (e.g., fossil carbon industries).

(2) Climate risk is also relevant for global financial stability. This threat to global financial stability is due to two factors. One is the correlation between climate change impacts and the other interconnectedness of national institutions and economies. For this reason, climate risk is also a central topic not only for firms but also for financial policymakers such as central banks and financial regulators.

Since the 2015 Paris Agreement, the financial sector has been increasingly engaging in the conversation on climate change. In article 2 and 9 of this agreement for the first-time finance was cited:

[10] https://www.bankofengland.co.uk/knowledgebank/climate-change-what-are-the-risks-to-financial-stability

“Making finance flows consistent with a pathway towards low greenhouse gas emissions and climate-resilient development[11].”

“Mobilizing climate finance from a wide variety of sources, instruments, and channels, noting the significant role of public funds[12].”

Starting from the Paris agreement, several initiatives have emerged to underline the importance of climate-related financial risks. These initiatives, some European and some global, are:

(1) 2017: the G20 Financial Stability Board (FSB[13]) launched the Task Force for Climate-Related Financial Disclosure (TCFD).
(2) 2017: the Network for Greening the Financial System (NGFS).
(3) June 2020: publication of the EU Taxonomy regulation in the Official Journal of the European Union.

Regarding the topic of disclosure of climate change risks, and the need to have metrics to assess risks, TCFD is used as the primary reference. TCFD develops voluntary and consistent climate-related financial risk disclosures for use by companies in providing information to investors, lenders, insurers, and other stakeholders.
The Task Force's first recommendation is that an organization's disclosures must be focused on the resilience of the strategies plan using different climate-related scenarios, including a two degree or lower scenario.
An organization needs to state also how the strategies to plan could be modified in response to the rise of climate-related risks and opportunities. The merit of the TCFD is to place scenarios as a central topic better to understand the potential financial implications of climate change. The TCFD “*core elements of recommended financial disclosure”* are described in Table 2.

[11] Paris Agreement (2015) Article 2, C.
[12] Paris Agreement (2015) Article 9
[13] FSB is an international body that monitors and makes recommendations about the global financial system, including all G20 states, FSF members, and the European Commission. It monitors and makes recommendations about the global financial system.

Metrics and Targets	The metrics and targets are used to assess and manage relevant climate-related risks and opportunities.
Risk management	The process used by the organization to identify, assess, and manage climate-related risks.
Strategy	The actual and potential impacts of climate-related risks and opportunities on the organization's business, strategy, and financial planning.
Governance	The organization's governance around climate-related risks and opportunities.

Table 2: *Core elements of recommended related financial disclosure. Source: TCFD (2017).*

These relevant and unprecedented international initiatives (i.e., TCFD, NGFS) have shown how climate change has become central for the financial stability agendas and has placed it as one of the main topics of the mandates of financial supervisors. Financial supervisors now explicitly recognize climate change as a new source of financial risk and are interested in making the financial system resilient and informed of these risks (NGFS, 2019; Bolton et al., 2020).

As a result, there is an increasing interest of the financial institutions in:

(1) investment opportunities that follow climate mitigation objectives.

(2) knowledge of the consequences for risk management of both physical and transition risk management.

As described in Table 1, there are two main types of risk. These two categories are also the two channels of risk transmission to financial stability. This aspect is due to a chain of effects described in Table 3.

For what regards climate transition risk, the principal hazards for financial stability derive from a disorderly transition to a greener economy (NGFS (2019)), and so in a scenario

where investors fail to anticipate and evaluate the possible impacts deriving from new climate policies changes (Battiston et al. (2020)).
Firms whose revenues derive or depend on fossil fuel are more straightforward examples of institutions that could have the worst impacts. These will suffer losses, deriving from assets that will have a change in value. These assets are called stranded *assets*[14] defined as:

"Assets exposed to devaluations or conversion to 'liabilities' because of unanticipated changes in their initially expected revenues due to innovations and evolutions of the business context, including changes in public regulations at the domestic and international levels[15]*."*

These losses derived from stranded assets negatively impact the value of the firms' financial contracts and the financial portfolios exposed to those firms. Therefore, banks and equity or bondholders are directly involved through the loans.

Climate physical risks	(1) Damage physical assets. (2) Damage firms' production capacity. (3) Increase credit risk of banks. (4) Increase financial losses for the insurance sector. (5) Impair governments' financial position.
Climate transition risks	(1) Unanticipated and sudden adjustments of asset prices (2) Changes in defaults probability for asset classes (3) Financial shocks for asset managers/investors/banks

Table 3: *Chains of the effect of climate-related risks. Source: a personal reworking of NGFS (2019)*

[14] Leaton, (2011); van der Ploeg and Rezai, (2020)
[15] IPCC (2014) Annex II

Starting from the chain of effects in Table 3, given the fact that the financial supervisor's objective is to maintain financial stability, it will be in its interest to give incentive for actuating an orderly transition and, more precisely, to stimulate a reallocation of capital flow into activities that involve low carbon usage. The time for a mitigation of the effects of climate change is limited, and the later this mitigation takes place, the faster it must take place. Hence while time passes, the possibility of an orderly transition decreases. Therefore, the impacts of physical risk increase due to the rise of climate changes related hazards deriving from a nonapplication of emission reduction. In this sense, climate transition risk and physical risk are correlated. If all the economic actors assess the transition risk, this will reallocate the capitals and neutralize the effects of transition risk. In contrast, the physical risk could be reduced with adaptation and mitigation in the long term but could not be eliminated. The NGFS gives a recap of the possible impacts on financial investments and summarizes four possible scenarios into a matrix (fig. 1 below).

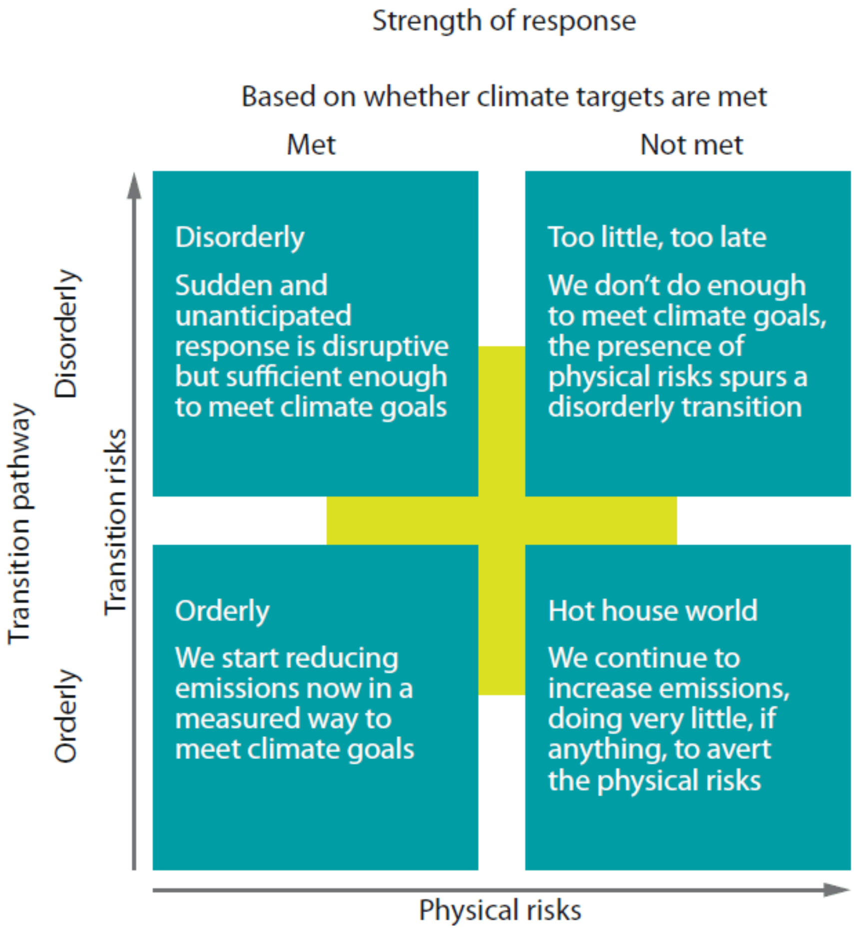

Figure 1: *NGFS matrix on four scenarios based on physical and transitions risk. Source: NGFS (2019).*

When we talk about risk deriving from climate change, whether related to physical risk or transition risk, there is an increasing need for all the actors in the economy (e.g., firms, investors, governments) to assess the impact and magnitude of this risk on their financial position. However, this risk assessment is challenging, considering that analyses based on the past are not helpful in most cases.

Climate change risk has specific dimensions that differentiate it from other financial risks; these come from the nature of this risk and its deep uncertainty. Different research analyzed these features. The references used are the McKinsey Global Institute Report (Woetzel et al. (2020)) and Battiston et al. (2019).
Battiston et al. (2019), in an analysis of the risk of the transition, highlights three specific points (deep Uncertainty, non-linearity, endogeneity of the risk). While the McKinsey Report (Woetzel et al. (2020)) focuses on physical risk, which is also the main topic of this thesis, it adds five other characteristics to uncertainty and non-linearity (spatial, increasing, systemic, regressive, under-prepared).

Deep uncertainty in making forecasts related to climate change derives mainly from the different variables involved. Climate change impacts on the economy will depend on multiple factors such as the policymakers' choices to reduce greenhouse gasses and, more in general, mitigation strategies and the development of adaptation strategies.

These two points are complex, and there are difficulties when a forecast of future states is necessary to identify a scenario to conduct an analysis. Policy progress could be slow or fast, and the same is for the development of technology that could help adapt to global warming and other hazards related to climate change. However, even if a probabilistic forecast is necessary to measure the risk associated with this unprecedented change, it cannot be made. The only way to overcome this problem is to make assumptions and reasoning by emission scenarios. There is a strict dependence on short-term action and future impacts in this sense.

Furthermore, the uncertainties related to climate change derive mainly from the earth system's nature and two specific features: tail events and tipping points.
One example related to tail events is the effects of global warming. Analysis of climate change usually gives data about mean temperature growth, such as the average rise in

temperatures over a horizon of time. However, more dangerous effects are caused by the change of extreme temperatures (and more in general by extreme weather events) present in the tail of temperature distribution. As described in Figure 2, a slight shift in the average can be related to dramatic changes at the extreme.

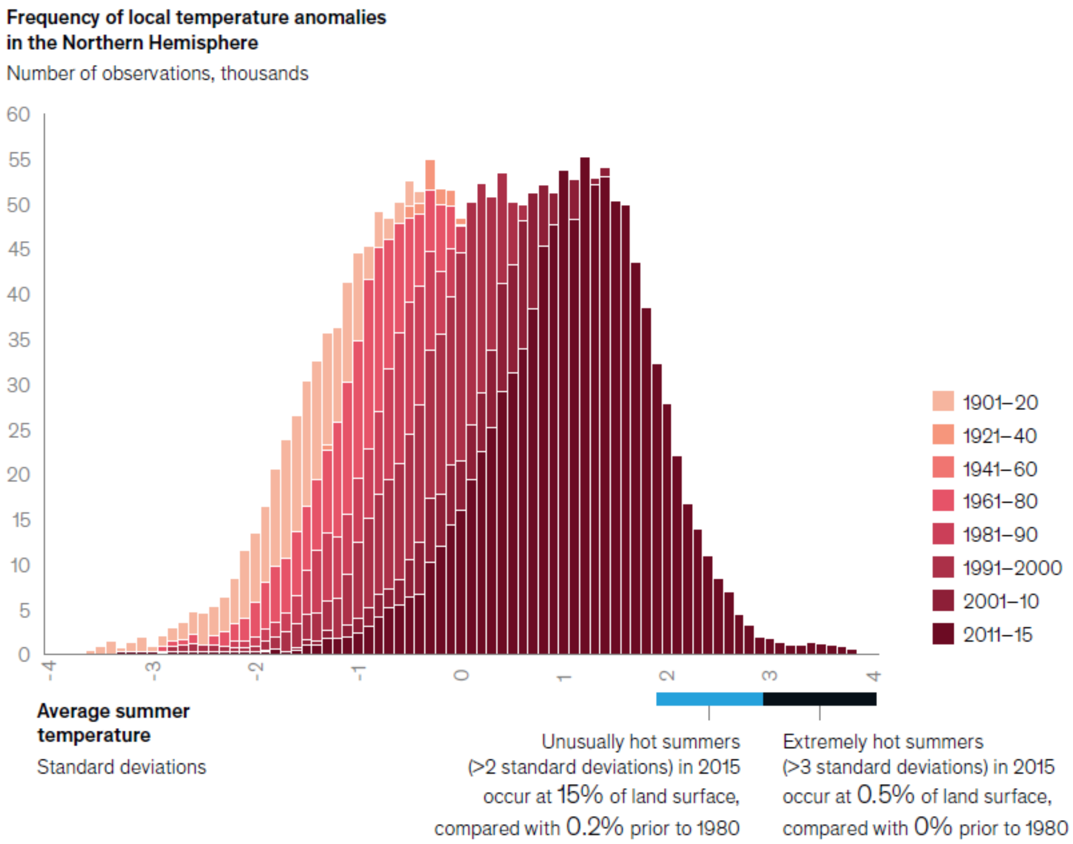

Figure 2: *Distribution of temperature in the Northern Hemisphere in different periods. The chart describes a shift in the mean and changes in shape due to tails fattening. Source (Woetzel et al. (2020))*

Figure 2 describes the evolution path of the temperature distribution in the Northern Hemisphere on different years periods from 1900 to 2015. From the figure, we can observe that not only is there a shift in mean temperature, as it goes to higher temperatures through the years, but it is also clear a fattening in the tails. From this, it can be derived that the mean days are becoming warmer and that, more relevant, extreme temperatures are becoming more probable and frequent. This aspect that usually goes unnoticed is crucial to risk analysis, and maximum temperature changes could generate more economic losses than mean temperature changes. When we talk about tail events rise probability, we refer to extreme temperatures and extreme weather events. These two are linked; an increase in extreme temperatures consequently increases extreme weather events probability. These hazards such as strong winds, floods, wildfires are expected to become more frequent with rising intensity. A higher intensity probability means that catastrophic events will be expected to occur soon. Still, forecasts about the magnitude of these events and the correct localization are impossible to be made.

Another challenge in applying analysis on climate change is non-linearity. The impacts related to climate change indeed will propagate in a nonlinear way. To understand the non-linearity of climate change is essential to introduce the concept of tipping point.
A tipping point in a system is a threshold that, when exceeded, causes a massive impact on the system's state, usually in an irreversible way. Tipping points are present in the climate system, but they are also present in the ecological system. These tipping points on the ecosystem are thresholds of different types (i.e., mean temperatures, maximum temperatures, water availability), beyond which a specific ecological system will start to work less efficiently or stop working. Ecological systems result from evolution and optimization for the historical climate's specific conditions. Adaptation of an environmental system is slower than the adaptation of an anthropological system. The perfect example is crops that grow only in regions with specific climate features. Crops have adapted to climate characteristics, but the current rate of warming is too fast compared to adaptation capacity. In this sense, culture cannot evolve at this current pace of mutation. Climate variable modifications could cause impacts even if these are small amounts.
Moreover, small shifts could also increase the probability of different extreme hazards (i.e., floods, wildfires, strong winds); this is an added source of potential non-linearities given the correlation of these two dimensions and the occurrence of multiple risk factors at the same time. The physical risk through the years, as global warming continues, will be continuously changing, so it will be non-stationary. Climate models predict that there will be further warming over the next decade due to inertia both from the geophysical system and a consequent "locked-in situations," but also from socio-technological inertia in reducing GHG emissions that will cause an even worse increase for decades.
This aspect is essential considering that even with a zero GHG emissions scenario, the warming and thus the risk will continue to increase due to thermal inertia in the earth system. Therefore, the risk will be in continuous escalation during the following years. Still, there are uncertainties regarding the pace of this increase. Non-stationarity is a

feature that is not common in past risk analyses. In this sense, it is impossible to make a standard analysis that goes from one scenario to another that will become the "new normal," but instead, there will be a situation in continuous change. Moreover, several actors of the economy will need to change the way they react to external changes. One of the consequences of a world in constant change is that the decision-making process, usually based on experience, could become less reliable than in the past; instead, business decisions based only on experience could become dangerous.

1.3 Case study: the future impact of climate change on the Italian wine sector

The purpose of this paragraph is to briefly introduce the main topics that will be described in the following sections of this thesis.

The wine industry is a challenging case study to understand the implication of climate change physical risk and how it could affect specific sectors of the economy. Viticulture is considered the "*canary in the coal mine of climate change*[16]." This statement is due to the high sensitivity of the production to climate conditions.
This thesis aims to analyze the implications of climate change in this sector.
The work will be mainly explorative, considering the small literature on the financial impacts of climate change physical risk in the wine sector. There will be a focus on individuating the chain of effects that, starting from climate change-related hazards, may affect the financial position of wine firms and credit institutions that finance these firms.

The work will focus on the Italian wine business. Namely, the topics treated are specific for wine production orientated towards quality; this feature has become one of the main drivers of the Italian wine international success in the last years (Sacchelli et al. (2016)).

The wine sector is one of the strategic sectors of the Italian economy. Italy is the first producer and exporter in volume globally, while France still maintains the first position

[16] Goode (2012)

if we consider the value of production. Data described in Tables 4 and 5 are taken from OIV (2021) *"State of the world of the world vitivinicultural sector in 2020"*.

mhl	2016	2017	2018	2019 Prov.	2020 Prel.	2020/2019 % Var.
Italy	50.9	42.5	54.8	47.5	49.1	3%
France	45.4	36.4	49.2	42.2	46.6	11%
Spain	39.7	32.5	44.9	33.7	40.7	21%
USA	*24.9*	*24.5*	*26.1*	*25.6*	*22.8*	-11%
Argentina	9.4	11.8	14.5	13.0	10.8	-17%
Australia	13.1	13.7	12.7	12.0	10.6	-11%
South Africa	10.5	10.8	9.5	9.7	10.4	7%
Chile	10.1	9.5	12.9	11.9	10.3	-13%
Germany	9.0	7.5	10.3	8.2	8.4	2%
China	*13.2*	*11.6*	*9.3*	*7.8*	*6.6*	-16%
Portugal	6.0	6.7	6.1	6.5	6.4	-2%
Russia	5.2	4.5	4.3	4.6	4.4	-4%
Romania	3.3	4.3	5.1	3.8	3.6	-7%
New Zealand	3.1	2.9	3.0	3.0	3.3	11%
Hungary	2.5	2.5	3.6	2.7	2.4	-12%
Austria	2.0	2.5	2.8	2.5	2.4	-3%
Greece	2.5	2.6	2.2	2.4	*2.3*	-6%
Brazil	1.3	3.6	3.1	2.0	1.9	-5%
Georgia	0.9	1.0	1.7	1.8	*1.8*	2%
Other countries	16.8	16.5	18.1	16.6	15.4	-7%
World total	**270**	**248**	**294**	**258**	**260**	**1%**

Table 4: *The table describes the volume of wine production in the world in 2016-2020. Italy leads with almost 19% of the global output. The table is also helpful to underline the drop in production in 2017 in Europe caused by heatwaves in the summer. Source: OIV (2021).*

	Volume (mhl)		Value (mEUR)		Type	Vertical Structure in 2020		Variation 2020/2019	
	2019	2020	2019	2020		volume	value	volume	value
Italy	21.4	20.8	6 387	6 233	Bottled (< 2 l)	59%	70%	1%	-1%
					Sparkling	20%	24%	-2%	-7%
					BiB	3%	2%	27%	21%
	variation of -2.4%		variation of -2.4%		Bulk (> 10 l)	19%	4%	-15%	-8%
Spain	21.4	20.2	2 718	2 626	Bottled (< 2 l)	36%	65%	-2%	-2%
					Sparkling	8%	15%	-5%	-14%
					BiB	3%	2%	41%	23%
	variation of -5.9%		variation of -3.4%		Bulk (> 10 l)	53%	18%	-10%	-3%
France	14.3	13.6	9 794	8 736	Bottled (< 2 l)	71%	64%	-5%	-8%
					Sparkling	13%	32%	-13%	-19%
					BiB	4%	1%	13%	7%
	variation of -4.9%		variation of -10.8%		Bulk (> 10 l)	13%	3%	-1%	16%
Chile	8.7	8.5	1 716	1 595	Bottled (< 2 l)	57%	81%	0%	-6%
					Sparkling	0%	1%	-24%	-24%
					BiB	3%	2%	24%	20%
	variation of -2.2%		variation of -7.1%		Bulk (> 10 l)	40%	16%	-6%	-15%
Australia	7.4	7.5	1 829	1 787	Bottled (< 2 l)	43%	77%	-8%	-6%
					Sparkling	1%	2%	-22%	-18%
					BiB	6%	2%	12%	22%
	variation of 0.5%		variation of -2.3%		Bulk (> 10 l)	51%	19%	11%	14%
Argentina	3.1	4.0	682	655	Bottled (< 2 l)	54%	89%	5%	-6%
					Sparkling	0%	1%	-27%	-38%
					BiB	0%	0%	-1%	13%
	variation of 27%		variation of -4.0%		Bulk (> 10 l)	45%	10%	81%	35%
USA	3.6	3.6	1 254	1 147	Bottled (< 2 l)	34%	73%	-14%	-11%
					Sparkling	1%	4%	-2%	-4%
					BiB	2%	2%	-24%	-12%
	variation of 1.8%		variation of -8.5%		Bulk (> 10 l)	63%	21%	15%	0%

***Table 5**: The table describes the wine exports trends of the leading producer of wine. The values are expressed in volume (MHL) in the first column, while in the third and fourth columns, values are described in euros (mEUR). The following column describes a vertical structure of wine production, dividing the output into four main categories (Bottled <2l, Sparkling, Bag in Box, Bulk >10l). Indications on the variations between 2019 and 2020 on the vertical structure types are also given in the last two columns (variations in volume and value). Source: OIV (2021).*

CHAPTER 2 - CLIMATE CHANGE AND FINANCIAL RISK IN THE WINE BUSINESS

2.1 The impact of climate on the wine business

2.1.1 Wine sector

In this paragraph, we will discuss some features of wine production. The purpose is not to give a detailed description of the sector. Instead, we aim to identify the fundamental complexities to analyze the impacts of climate change on the industry properly.

The wine industry is a highly fragmented world. There is an excellent variety of customers, commercial channels (e.g., mass retail trade or Horeca), production processes, et cetera. A specific segment serves the intersections of all these factors, and there are no products that can be used as substitutes. Wine is the transformation of grapes; hence, when we talk about *"wine firms,"* it is not a raw agricultural product that is sold at the end but instead a transformation of that product. As mentioned before, the industry is fragmented, so it is helpful to describe the firms' structures in this sector. We can identify three main categories of winemaking operators:

- Farms processing self-produced grapes
- Cooperative wineries
- Winemaking industries processing purchased grapes.

Furthermore, Pomarici (2021) stated that we could find two main markets in the wine business. One is the external the other is internal. The two terms that individuate these markets refer to the agricultural production phase. Namely, external markets are markets where wineries sell grapes to winemaking industries or cooperatives (where these wineries are not members). While internal markets are those markets where grapes are transformed into wine internally, so are parts of this market the first two categories of winemaking operators: farms processing self-produced grapes and cooperative wineries that process member-produced grapes.

We can distinguish two main wine firm groups from these three categories of winemaking operators. The first group refers to wine firms that own the vineyards and directly produce grapes that then process and transform into wine. The second group comprises firms that buy raw materials, grapes, or direct bulk wine from other wineries and only follow the transformation process or bottling. A summarized supply chain of the two markets is represented in Figure 3.

In this thesis, we will focus on the first type of business, firms with owned vineyards, and we refer to high-quality products that are bottled and do not sell bulk wine.

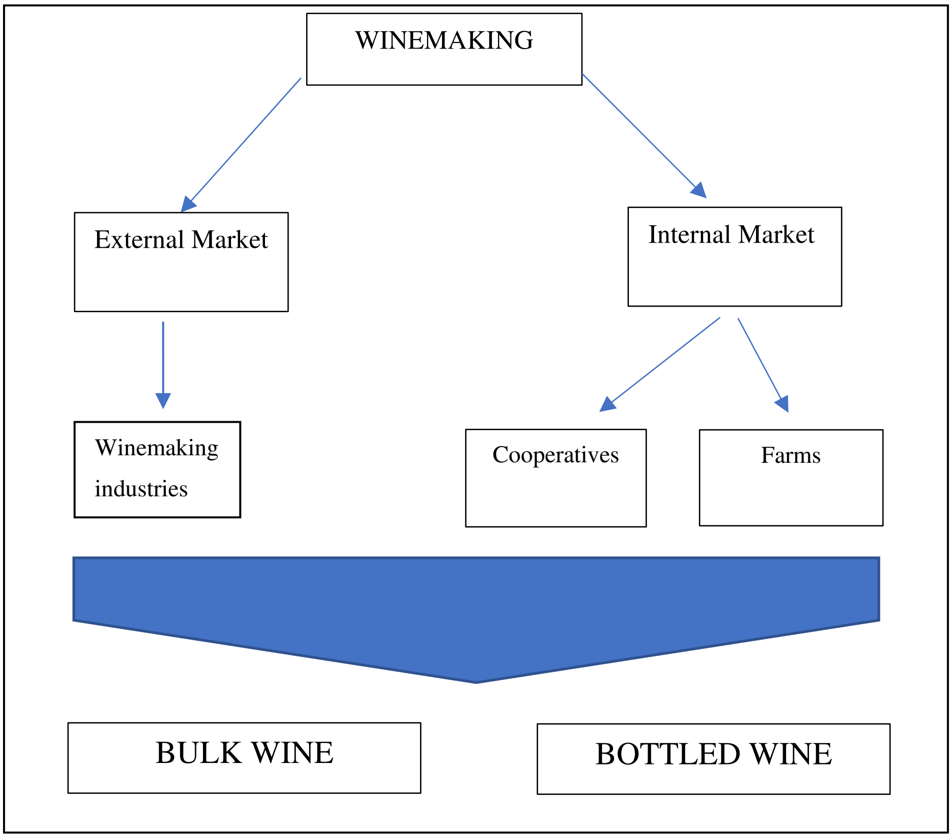

Figure 3: *Winemaking supply chain with the description of the two main Markets. Source: rework of Pomarici (2021).*

Figure 4 summarizes the Italian wine supply chain concerning the 2012 harvest. During this year, the internal market has a percentage in the volume of 70 The agricultural incidence in the winemaking process increases if the wine produced is part of some denominations; namely, we have an increase in PGI wines and even more in PDO wines. This increasing trend supports the fact that, on average, an agriculture chain is usually related to the final product's quality orientation.

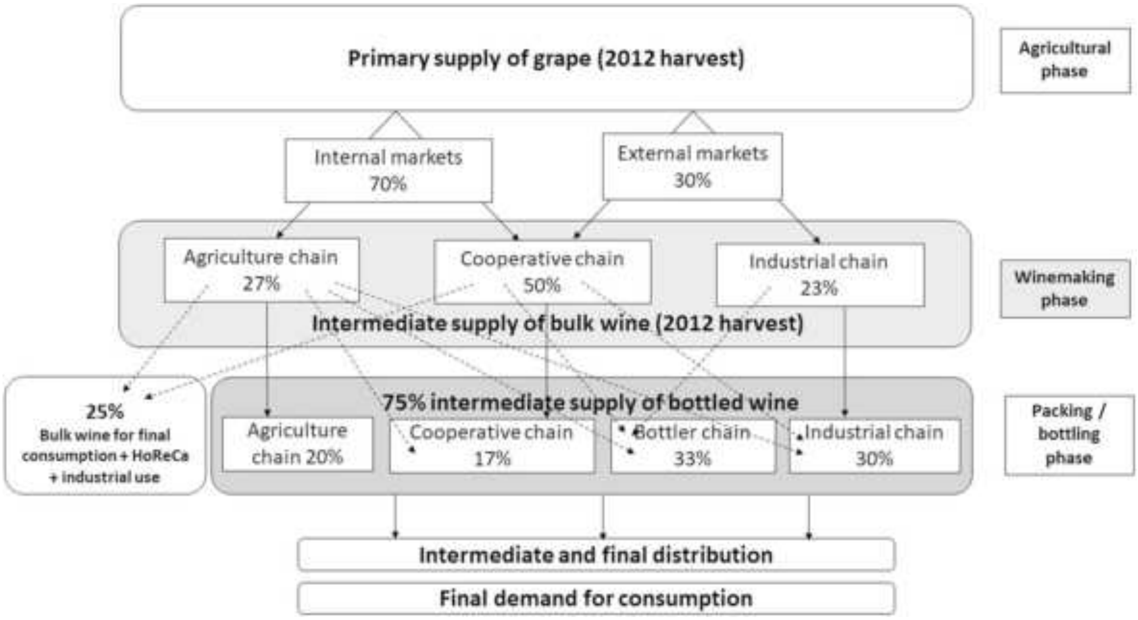

***Figure 4**: Value chain structure of Italian wine sector, 2012 harvest data. Source: Pomarici (2021).*

To present some dimensions of the wine sector, we organize some specific industry features into the following matrix in Table 6. Although, these features will be deeply analyzed in this paragraph, each point will have consequences related to climate change and will be resumed in the following sections of this thesis.

Features	Description	Weaknesses	Strengths
Transformation period	Period from harvest to sale. Usually directly proportional to quality	Cash flows take place several years after the harvest	Diluted/lagged manifestation of losses in case of bad vintages
Multiple labels	Diversification of the varieties and wine styles		Hedge effects
Wine firm orientation	Maximization of quantity and quality	Difficulties to center the optimum production mix	Broad market segmentation: possibility for the firm to find its niche
Pluriannual crop	Requires up to 5 years to enter the production phase.	Slow adaptation if there is an external mutation of the best conditions.	Resilience of the vineyard and quality of wine produced becomes higher the older the vineyard.
Terroir	Some locations have specific features that are not substitutable in the quality sense	High cost of vineyards and land in specific areas.	Unique features of the wine produced in particular areas.

Table 6: *Relevant wine firms feature with weaknesses and strengths points. Source: personal contribution.*

The first feature we introduce is the transformation period. It is different from aging or refinement, more often used in wine literature. We refer to the *"transformation period"* as the time from the harvest to the bottle sale. It could last from a few months to years, and this span depends on the style of the wine produced. This period is a sector feature that needs to be considered when making a financial analysis on a wine firm since it impacts its financial position. One of the consequences is that cash flows deriving from sales, through this range of time, are postponed concerning the strictly agricultural part that usually ends in August/September with the harvest. Therefore, a more extended time is needed to convert the capital invested into cash flows if we compare the wine sector to other agricultural industries. This lag in the cash flows realizations also coincides with a delayed appearance of bad results in low quality or low quantity vintages and hides the channel to associate the profitability of a specific year into financial results. In most cases, firms that produce high-quality wines deal with an even longer transformation process, so this delayed results phenomenon is amplified for these firms.

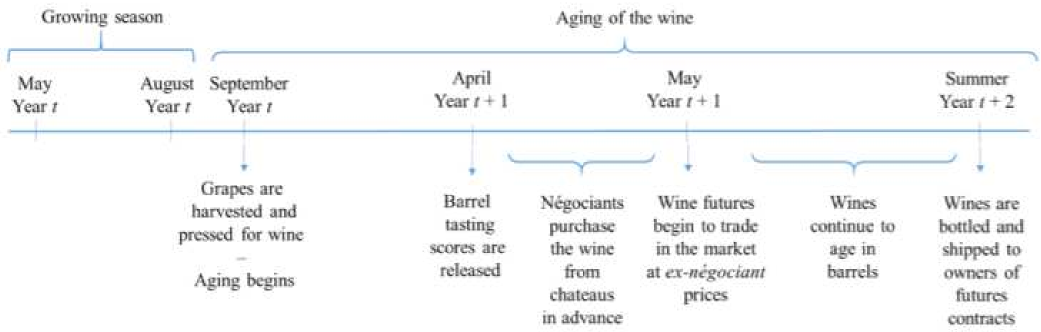

Figure 5: *A timeline of the supply chain of Bordeaux Wine, a purchasing method "En primeur". Source: Hekimoğlu and Kazaz (2020).*

Furthermore, high-quality wines produced in Italy have complex selling methods due to the low quantity produced and the high demand. These methods are like the ones used in France for fine wines. In fig 5[17] is described, for example, the Bordeaux supply chain of wine. This selling method helps to overcome the long conversion of capital invested into cash flows that, as we have seen before, is more acute in quality productions with a long transformation period. We now analyze this method. The first stage of the production process is the growing season from May to August. Grapes are then harvested and pressed in September. From this point, it starts the aging of the wine of vintage t in the barrels. Experts visit the winery eight to nine months after the harvest and release their tasting notes from a sample taken from the barrel in April of year t + 1. From this moment, wineries start selling wines to négociants, and so the cash flows derived from sales realization arrive before the bottling of the wine. Négociants then sell the wine purchased to an ex-chateaus price in futures contracts at an ex-négociant price. At least 80% of Bordeaux wines are traded as wine futures in the summer of year t + 1. In addition, some wineries put in a time of refinement not in the barrel but directly in the bottle. This added time frame depends on the winery policy, and the final customer could also do this added refinement. In this purchasing method, the firm's fulfillment of the cash flows happened before the end of the transformation period.

Besides the duration of the transformation process, another peculiarity of the wine sector is the diversity of characteristics that the final product can have. As mentioned before, there are different segments in the target customers of the wine sector. Depending on the dimension, a single firm may serve more than one of these segments. Winemaking firms

[17] Hekimoğlu and Kazaz (2020).

usually have more lines of wines with different characteristics, not only in terms of duration of the transformation process but also in grapes varieties used and winemaking technique adopted. Multiple labels production is a peculiar factor of the winemaking industry. This aspect can be defined as the possibility to produce different wine types starting from the same raw material, grapes. For example, from a specific white varietal grape (e.g., Chardonnay), a winemaking firm could produce a sparkling wine (with different methods: Charmat, Classic, PetNat), an orange wine with maceration on the skin, or a simple still white wine. With multiple labels production, it is possible to diversify the production. In this sense, diversification helps the firm become more resilient to the different sources of uncertainties typical in the wine sector and, in general, agricultural production, which will be deepened in paragraph 2.1.2. The choice of the winemaking technique (i.e., the label's choice) is made at the end of the harvest. This choice made at the end of the harvest gives a certain degree of flexibility.

In other agricultural commodities, usually, the only goal of the firms is the maximization of the yield of the production. For wine, this is not sufficient since a high yield can result in low quality of the final product. For a wine firm, the objective is the maximization of two aspects. These are yield (or quantity for a given surface of land used) and the quality of this yield. A simplification of this aspect could be that the focus of mainly one or the other is determined by the segment of the markets the firm serves so that a producer could have an orientation through quality production (i.e., bottled wine) or quantity production (i.e., bulk wine). In this sense, there is an ambiguity if we think about the agricultural production objective of maximization of the yields, given that usually, a low yield in the harvest is considered a high-quality characteristic of wine. The quality of a wine and, consequently, the price of a bottle come from many variables. For this diversity driven by the combination of these variables, wine can be considered one of the more complex agricultural sector products. It cannot be taken as a standardized commodity. Therefore, this diversity in the final product, also regarding the possibilities of different label production and different choice of the transformation process, gives, as stated before, a broad market segmentation. In this sense, the positive points are that there is a high possibility for the firm to find its niche in the market that maximizes profits, while the negative aspect is that it is not easy to find the proper equilibrium in the production process through an orientation towards quantity and quality maximization.

Another feature of wine production derives from the pluriannual nature of the vine. The grapevine is a pluriannual crop that deserves up to five years to enter the production phase. The wine produced from old vines is furthermore considered a positive characteristic in wine prices by customers because this is associated with low yields production and higher vintage quality[18]. One issue related to the pluriannual nature of the vine is the fixed capital invested and consequently limited flexibility if there is a need to change the production in response to external mutation of the past conditions (e.g., climate change or modification of the market trends). This aspect is particularly harmful if divestment is made during the first stages of a newly established firm when the costs are not already transformed in cash flows (Cadot (2013)). Indeed, cash flows are postponed for years when a new vine plant investment is made.

In a winemaking firm that produces high-quality bottled wine, vineyards are one of the essential tangible assets in the balance sheet. The value of vineyards can be very different depending on their location. One of the determinants of the price of a hectare of the vineyard could be considered the ***"terroir."*** The concept of terroir, however, does not have a clear definition, but it could be summarized with the description given by Cambridge Dictionary, where it is described as:

"The special character that wine is thought to get from the particular place where the grapes were grown to make it. The idea of terroir is the notion that topography, soil, and climate can make two wines taste different, even if those wines were made from the same grape and grown within a football field of each other".

Terroir is a specific feature of the agricultural wine process. Moreover, it is a factors combination that, with a correct mix, gives the best conditions for the cultivation of a specific variety of grape, given a wine style that a winemaker wants to follow. The factor that will be analyzed more deeply in this research is the climatic factor that is probably

[18] https://www.theguardian.com/food/2021/may/16/do-old-vines-really-make-the-best-wines
https://www.winemag.com/2016/01/21/why-you-should-discover-italys-old-vine-wines/
https://www.nationalgeographic.com/travel/article/ancient-wines-are-having-a-moment-in-italy-heres-why

the one that could change more rapidly if compared with the others (e.g., soil composition).

Terroir is also used to be more competitive in the market. Vaudour (2003), Elaydi et al. (2012), and Clingeleffer (2014) explain this aspect widely. In addition, terroir is related to the organoleptic features of the wine. In this sense, it is also helpful in marketing and commercial strategies to incorporate a sense of the land into the business and link the bottles of wine with a community's uniqueness. This uniqueness is essential to deliver a more competitive product sold at a premium price.

One of the proofs of the terroir concept translated in monetary terms is the variability of price per hectare of a vineyard concerning the place where these vineyards are located. The main database for the value of vineyards in Italy is the one made by CRE part of the 2018 values are expressed in Table 7. In these data of 2018, the more valuable area is the DOCG in Barolo (with a maximum of €1500k per hectare). Other specific sites reach maximum value over €400k per hectare (DOC Lago Caldaro, DOC Valle Isarco, DOCG Montalcino, DOC Bolgheri). These values are in continuous expansion, and some suited areas almost doubled the value in 5 years from 2013 to 2018. This is the case of one of the last trending areas for high added value wines, the DOC Etna. These data also certify how in 2018, there was an overtaking in terms of average land values per hectare of vineyards on land dedicated to fruit and vegetable crops.

This highlights the status of such specific culture, even more considering that the value of an orchard in Italy was almost double the value of a vineyard only twenty years earlier. It needs to be noted that the land values described before and in Table 7 refer to land and entire farms for which a significant purchase and sale activity has been recorded. In this sense, these are conservative data. Larger values are present in suited vineyards on the denominations on the table.

Main DOC and DOCG Italian Areas	Min Value €/hectare	Max Value €/hectare
Vineyard on DOCG Barolo Langa di Alba (CN)	200.000	1.500.000
Vineyard on DOCG Colline di Montalcino (SI)	250.000	700.000
Vineyard on DOC Lago di Caldaro (BZ)	440.000	690.000
Vineyards on DOC Bassa Val Venosta (Naturno BZ)	440.000	690.000
Vineyard on DOC Valle Isarco Bressanone (Varna BZ)	440.000	690.000
Vineyards on DOCG Valdobbiadene (TV)	300.000	450.000
Vineyards on DOC Bolgheri (LI)	200.000	400.000
Vineyards on DOCG Colline di Asolo (TV)	250.000	380.000
Vineyards on DOCG Chianti Classico (FI)	100.000	150.000
Vineyard on DOCG Chianti Classico (SI)	90.000	150.000

Table 7: *Valuation of the main Italian terroir (DOCG and DOC denominations). Source: CREA (2018).*

This overview underlines the differences in the values of the assets in the balance sheet of a wine firm. It also highlights how much variability there could be in those values. The concept of terroir is also strictly related to the quality of the final wine. Fine wines with high added value are produced in specific areas selected in the years by winemaking critics, customers, cultural aspects, and trends in the tastes.

The terroir concept gives us also an idea about the difficulty of changing the location of vineyards given the strict bond that some places have with the production of quality wine. Some areas are a prerequisite for high standards of quality that could not be reproduced in other sites.

From this small introduction about the features of the wine sector, complexities related to this sector have already emerged. These complexities represent a challenge whenever the wine sector analysis is necessary. It is not easy to extract general information from a highly segmented market without bias. For example, conclusions that could be applied to big, diversified firms that produce bulk wine could not be appropriate to small farms with niche and high-quality products. For this reason, we decided to pose our analysis on a specific segment of this sector: the high-quality production (with bottled wine and not bulk wine) with owned vineyards.

2.1.2 Uncertainty and risk management

Some of the specific features of wine production have been analyzed in the previous paragraph. This paragraph will focus on describing the risks and uncertainties present in this sector. Furthermore, we will describe how climate change worsens the weather risks related to weather fluctuations.

Agricultural activities are, in general, subject to uncertainties. Moschini et al. (2001) find four primary sources of uncertainties identifiable in the agribusiness; some (production uncertainty and price uncertainty) are strictly related to the weather variability.

The first source is **Production uncertainty**. In an agricultural activity, we can consider the production function as a mix of the quantity and quality of the final output. This function is stochastic and depends on a set of variables. These variables are typically not known with certainty. One of the main factors that are not known in advance is the weather, which is at the same time the critical factor in agricultural production. These uncontrollable factors are heightened because time plays a crucial role in agricultural manufacture. Production lags are indeed dictated by the biological processes that underlie the production of crops.

Price uncertainty is another source associated with agribusiness. Due to the production lags already mentioned, production decisions must be made in advance according to biological cycles. This advanced choice causes an asymmetry regarding the output price that is unknown when these production decisions are made. In addition, price uncertainty is more relevant because of the inherent volatility of agricultural markets. Such volatility derives from demand fluctuations, which could be particularly important when a significant portion of the output is exported to other countries. Also, production uncertainty contributes to price uncertainty because the price needs to be adjusted regarding the demand and the supply. In this process, some typical features of agricultural markets such as the presence of many competitive producers, a homogeneous output (as described before, this is not the case of wine), and inelastic demand are responsible for creating considerable price volatility, even when a moderate production shock hits the supply.

The other two sources are **technological uncertainty** and **policy uncertainty**. The first is related to the evolution of production technologies that may make past investments obsolete. The second is associated with the possible changes in the policies related to the sector. These sources of uncertainty are also commonly present in other sectors.

All these sources of uncertainty cause some risks. Risks that affect the agricultural sector could be divided by the dimensions of revenues touched[19]. The sources of risks could be split into two main groups: risks that cause a yield reduction and risks that cause an input or output price change. One of the main risks that affect agricultural production is the weather risk. This risk could result in a change in the two dimensions described before. Weather risk includes a vast set of related hazards such as drought, hail, and other extreme events that could affect the yield of a culture.

These hazards could have different natures. They could be divided into two smaller groups: symmetric or asymmetric.

A weather hazard is **symmetric** if, when it hits, the impact is widespread into a vast region or **asymmetric** if the effect is finite to a small area. Symmetric weather events could be, for example, drought, while an asymmetric event could be hail or floods that may be more adverse in specific restricted locations.

OECD (2009) underline the necessity of a holistic approach to deal with the agricultural sector's risks. It analyses three increasingly essential types of risks dividing them into layers. The first layer includes a systematic risk that does not significantly impact income losses. This first layer is usually managed directly on the farm. The second layer is a type of risk that is intermediate; it is asymmetric but could give a high amount of damage. For this second layer, some insurance products or market solutions could be acted. Finally, the third layer represents an infrequent risk but has catastrophic consequences. These

[19] OECD (2009)

catastrophic consequences, added with a situation of symmetrical impact, do not give possibilities for financial products that could manage the risks because usually, a market failure for these products happens. Related to this two main points of OECD (2009) can be cited:

1. *"Risk management strategies start with decisions on the farm and the household: on the set of outputs to be produced, the allocation of land, the use of other inputs and techniques, including irrigation, and the diversification of activities on and off-farm. Farmers can also manage risk through market instruments which include insurance and futures markets.*"

2. *"Not all risks are insurable through markets, the main reasons for non-insurability being the systemic nature, the lack of information on probabilities and information asymmetry concerning those probabilities."*

These two aspects are fundamental also in the whole wine sector. It just appears clear that insurance and financial hedging products are not sufficient to cover the weather risks. The prevention and reduction of these risks during operations are the primary risk management strategy that the firm could operate. Weather risk is one of the main risks in the wine business and, as considered previously more generally, in the whole agricultural sector.

One common trait in the different wine industry segments is the directly dependence on environmental factors such as climate conditions. Grapevine production is sensitive to climate conditions. These could modify the harvest quality and yield. An abundance of climatic variables could alter these two dimensions with a slight shift.
Due to sensitivity regarding quality, viticulture is considered as *"a canary in the coal mine for climate change"* (Goode (2012)). Climate change could impact changing the environmental variables that are strictly related to one of the firms' core businesses, the agricultural process. Change in quality and yield of the harvest and, more in general, the variability of these two dimensions is normal for the business; this represents, in any case, a source of risk determined before as weather risk. However, climate change exacerbated this phenomenon.

The climate change process could already be perceived in the whole sector in specific outliner vintages. This ongoing process causes some practices changes. These practices are consolidated through the years. The changing pattern comprises the productive part (work in the vineyard) and the transformation part (in the cellar). One of the more evident aspects of the business's strictly operational and agricultural part is the start of the harvest. In the last decades, an earlier harvest time has been registered. In general, this is a sign of early maturation due to higher temperatures in the ripening months. Figure 6 reproduces a graph with the start of the harvest for the top label of Ornellaia: Masseto. This label produced in the Bolgheri DOC denomination area is considered one of Italy's top fine wines[20]. From Figure 6 we can state a clear trend of earlier harvest dates from 1985 up to now. Data is taken directly from the website; however, it is not common for a wine firm to disclose this type of data. For this reason, only the Masseto's harvest is reported on the graph.

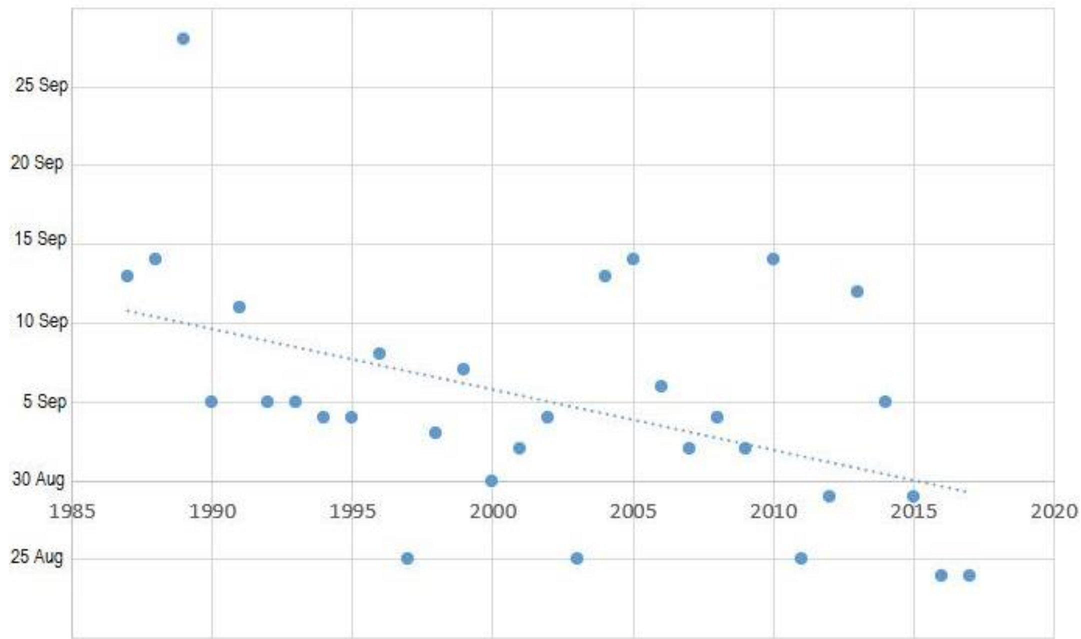

Figure 6: *Starting harvest date in Masseto vineyard, clear decreasing trend. Source: rework of data on www.masseto.com*

[20] https://www.wine-searcher.com/find/masseto+tuscany+igp+italy/1/italy

These changing patterns in the wine business, related to climate change, could influence the revenues of this industry; the magnitude of this influence in the future is challenging to assess, given the non-linearity of the possible impacts. However, there will be an increasing need for adaptation strategies to cope with these risks of losses.

Sacchelli et al. (2016) analyzed the studies on the impact of climate change in the wine sector. These result as a recent and emerging topic. The interest in adaptation strategy emerged only recently, while, differently for risk assessment, there is a lack of research based on uncertainty. Sacchelli et al. (2016) also find that terroir and quality-related studies appear to be a country-specific topic related mainly to Italy and France and suggest for future research an:

"integrated assessment of climate change impact on wine industry to assess the wine sector as a complex and nonlinear system"

and

"in-depth risk computation and the evaluation of uncertainty related to implemented scenarios."

Climate change has an impact on different dimensions of the business. One dimension is simply the quantity of wine produced. We will see in the following paragraph that the direct consequence is a decrease in crop yield and thus a smaller number of bottles of wine produced and a worsening in the quality of the production.

Quantity and quality issues related to climate change will be explored in paragraphs 2.1.4 and 2.1.5 respectively. At these two dimensions, we could add other elements that are indirect consequences of climate change some of them are explored in the next paragraph 2.1.3.

2.1.3 Indirect climate change hazards

There is an abundance of events caused by indirect effects of climate change that could influence the sector revenues of wine and the impact on the value of vineyards. Two typical examples of the hazards of this sector that will be more present in the future due to climate change are wildfires and vine pests. However, both these two types of hazards are difficult to be assessed in a future perspective. This issue is common for other similar indirect costs of climate change due to their unprecedented nature.

Due to climate change, there is an increase in wildfires' probability caused by heatwaves, drought, and higher temperatures. This increasing probability is stated in different studies (i.e., Overpeck et al. (1990)). Such trend has also manifested recently, in 2020, in one of the more important areas for American viticulture, Napa Valley, which was hit by massive wildfires with damage in some vineyards, giving different outcomes in losses (Wilson (2020)).

The damage from wildfires could be directly on the tangible assets with damage on vineyards. In Napa Valley, there were also quality problems with the vintage. However, wineries that could harvest may not produce the vintage due to smoke effects on the ripening wine grapes. This phenomenon is known as *smoke taint*, and it is analyzed in different studies usually related to Australian vintages (Howell (2008)). Kennison et al. (2007) also observed an increased ethanol concentration and browning related to wines made from grapes exposed to smoke. Therefore, we can deduce that when massive wildfires hit wine areas, also when the vineyards are not directly affected, there could be damage to the quality of the outcome, which expands the areas of damage also to vineyards not directly hit by fire.

One of the consequences of global warming is the increasing probability of vine pests. This effect is not usually considered the same importance as the other described in this research. However, the consequences of diseases could be catastrophic. This factor may directly influence grape production for many years. Some studies confirm that increasing temperatures could help the propagation of some illnesses or could modify the areas where some diseases hit vineyards. One of the most critical propagations of disease studied is Pierce's disease caused by Xylella Fastidiosa. This is an example of a disease that has vectors that are highly dependent on temperature; in particular, warmer winter temperatures could help to spread to northern regions the propagation of this disease (Daugherty et al. (2009); Martensson (2007)).

2.1.4 Impacts on quantity (Yield)

Quantity is the more straightforward of the two categories of dimensions modified by climate change. Differently from quality, quantity can be assessed precisely during the grape harvest.

While easy to assess, the quantitative data concerning an economic analysis of the vintage outcome are challenging to analyze. Firms need, as said before, to consider both quantity and quality. However, these two factors are considered dependent on the other in some sense. In the years, the belief in the enological research was and still is that a low yield is necessary to produce high-quality wine. There is the supplement that in wine laws, for example, in Italian and French denominations, a threshold of maximum yield is fixed to be certified by some denominations. This aspect, therefore, is not the other way around, so a yield decrease is not always a sign of high-quality wine.

This aspect of complexity is usually forgotten in economics analysis regarding climate change effects on viticulture, and this is highlighted in Ashenfelter et al. (2014), where explains that one of the limitations on climate change impacts research is that:

"Many studies consider only partial equilibria and disregard interdependent relationships between crop yield, quality, and price."

The ProWein Business Report (2019)[21] surveyed 261 small wineries and 51 cooperatives interviewed, mainly from Europe. The results state that 59% of participants reported reduced yields due to extreme weather events such as heavy rains or hail and that 52% reported increased volatility of grape yields. This result was registered in the five years preceding the interview, so the yield change is reported in 2014-2019.

Many studies indicate that an increase in temperature due to climate change will decrease the harvest yield. For example, Goode (2012) highlighted that:

"Even small shifts in growing-season temperatures show up as marked differences in flavors or yields."

[21] Survey available at www.prowein.de

There are also reported data of decrease in the yield for the vintage 2012 where France suffered a 20% drop in wine production, due to a higher temperatures season, while Italy sustained a 7% (but compared with another bad vintage in 2011). The data, already engaging in the aggregate forms, result in much more interest if disaggregated in the various wine regions. Three of the most important areas of France's fine wine report even more significant shifts: in the Loire Valley, there was a drop of 50%, a 40% for champagne, and a 30% for Burgundy. These variations suggest that analysis regarding climate change should be done at a small spatial resolution, given the different impacts that a weather change can have on different locations. Moreover, Kliewer (1977) analyzes various international cultivars such as cabernet sauvignon and pinot noir and compares different temperatures. The studies find that over the benchmark of 25/20 degrees, there are increasing consistencies that rising temperature in the bloom period plays a crucial role in fruit–set, ovule fertility, and berry size. These findings suggest two main things. One is that there exists a varietal specific optimum regarding crop yields and that over a threshold, this results to be reduced. Then, besides the capacities adaptations of varieties, there is a decrease in yield over the threshold of 20-25 degrees. This threshold suggests a nonlinear relation between increasing temperatures and yield. More precisely, it underlines that the change in extremes of the temperature distribution is probably more impactful than a change in average temperatures.

2.1.5 Impacts on quality

Many characteristics define wine quality: Color, acidity, alcohol content, body, and varietal aromas. Some of these derive from chemical reactions in the ripening process of grapes, others derived by the fermentation, elevation, and refinement techniques used.
The characteristics that come from the ripening of grapes are strictly related to climate, even if the subsequent stages of production could modify these characteristics. In this paragraph, we summarize the effects on the quality that could happen due to climate change. In paragraph 2.1.3, we already talked about the smoke taint and the possible effect of wildfires on wine quality. This paragraph mainly describes the implications of increasing temperatures and other topics related to climate change, such as the higher probability of heatwaves and soil dryness.

As we have seen before, the concept of quality is fundamental for price positioning in the market. Therefore, it is straightforward that usually, higher quality leads to higher bottle prices and higher revenues for the firm.
Recalling the concept of terroir explained in paragraph 2.1.1, each region and sometimes each land/village in Italy has a different wine style and varietals, chosen in the years from the combination of soil and climatic conditions (Santos et al. (2020)). For these varieties, there are high margins of adaptation. Still, it is not easy to copy the same wine style and organoleptic characteristics in a land that is not autochthonous for the specific wine produced. There is an abundance of terroir-related scientific studies well summarized in Vaudour (2003). The terroir is considered one of the major determinants of high prices in fine wine. The zoning of terroirs has historical importance and customer recognition. The concept of terroir is strictly related to climate. This interconnection is a threat to the entire sector if we consider the significant change in temperatures we have had in the last years and much more if we think about the projected scenarios of these changes. Climate change could have a higher impact on the segment of the wine industry that has the higher added value. Wine regions have been selected in the last centuries due to the particular condition and symbiosis that the soil and climate have; what will happen when these conditions change?
Referring to this rising question about the future of viticulture, the IPCC, in one of his reports (02/2018), gives projections in this sense with a benchmark of confidence, more precisely, it states that:

"Climate change will modify the geographic distribution of wine grape varieties (high confidence), and this will reduce the value of wine products and the livelihoods of local wine communities in Southern and Continental Europe (medium confidence) and increase production in Northern Europe (low confidence)."

One of the first things to observe, highlighted in the IPCC report, is that climate change could not only have negative perspectives. If we assume, with evidence, that all type of wine grapes has an optimum climate condition, a change of these parameters due to climate change in the world would probably result not in symmetric shock. For example, there could be surprisingly positive effects in some areas that could not fully ripen grapes without climate change. In this sense, in cold climate areas, the number of good vintages (in a quality sense) may be increasing for some years, while in areas where the temperatures were already at optimum, there will be a decrease of good vintages. This aspect is widely explained in Ashenfelter et al. (2014) that in the final summary of their research underline that:

“Rising growing season temperatures can be beneficial or detrimental to viticulture. As a result, there will be winners and losers from climate change.”

In Italy, there could be some opportunities for new vineyards planted in higher altitudes in areas that were not considered suitable for these productions in the past (Boselli et al., 2016). Conversely, according to this study, there will be fewer opportunities related to the shift of the cultivation to the northern regions. However, considering the concept of terroir and the rigidities that this factor induces, it is easy to assess that there will be more negative aspects than positive ones. Besides the terroir aspect that could be lost through climate shift, it is also essential to highlight the correlation between climate and prices in wine. As evidence of the remarkable bond between a good vintage and climate, Ashenfelter (2010) shows indeed that the variability of prices in Bordeaux vintages is explained, in part, by the weather variables of the year tying the cost and quality of fine wine with the climatic conditions. This relation is substantial evidence that the price of the final product is linked with climatic conditions for fine wines with high added values.

After introducing the main topics related to climate change and the quality of wine, we pass now at the end of this section to consider the more direct effects of climate change on quality, reviewing the literature about this topic. One of the periods that contributes mainly to the development of the quality of grapes is the ripening stage during véraison (the moment when the berries color changes) and maturation. In this stage, the temperature affects the acidity and sugar ratio of the grapes but also other aspects such as color and flavor profile; these effects are described in Mira de Orduna (2010), where there is also highlighted the problem of the chemical modification of varietal aroma compounds due to excessive heat accumulation.
It is well known that a higher temperature leads to an increase in sugar content on berries while reducing the grape acidity. In the transformation stage, this aspect determines a lot of qualities characteristics of wine, such as the style, the balance, and the alcohol content.
The sugar content on berries is responsible for the potential alcohol content of wine. At the same time, acidity has enormous effects on the longevity of a bottle of wine if grapes

are used to produce wine that is destined to be aged. Sadras et al. (2012) have confirmed the importance of temperature on the development of acidity and sugar in berries using a field experiment.

Higher wine alcohol deriving from an increased concentration of sugar in grapes contrasts with wine market trends for lighter wine compared to the past. In general, customers are pressing to decrease the alcohol content without altering the organoleptic characteristics (McIntyre et al., 2015).

One of the studies that tried to take data from the past to explain the change in alcohol content of wine was Alston et al. (2011). The research analyzed the content of sugar in California wine grapes. It found an average increase in the sugar content, measured in Brix, from 1980 to 2005, of 0.23% per year. This increase was more pronounced for red then white (red almost doubled the white). In the econometric analysis, Alston et al. (2011) found that rising temperatures have contributed to the higher sugar levels. However, not all the increase could be attributed to climate change. A part could be explained by market trends in the '90s for high body wines (e.g., Parkerization). Also, in Jones (2007), there are reports of increased alcohol content in wines from Napa Valley. However, the research attributes only 50% of the increase to climate change. The problem related to this higher projected alcohol content is also highlighted in Mira de Orduna (2010), where it is described that there has been an increase in alcohol levels above the 15%.

Related to grape sugar accumulation, one of the main consequences in productive operations is the trend of the last few years, as we see in paragraph 1.4, to anticipate the harvest time for avoiding an overripe of the berries.

The quality decrease is also studied in Mori et al. (2007), where it was found that there is a loss of anthocyanins in red wine under high temperatures. Anthocyanins are primarily responsible for the color of a wine. This is relevant because the color is considered a quality indicator present in the wine law of some Italian denominations. Moreover, Tarara et al. (2008) analyzed the anthocyanin's response to rising temperatures combined with the effects of solar radiation. The analysis was taken on a specific varietal, the merlot, that is present also in the Italian denomination of high-quality wines such as Bolgheri. In this research, citing the summary:

"Results indicate a complex combined effect of solar radiation and berry temperature on anthocyanin composition, synergistic at moderate berry temperatures and potentially antagonistic at high-temperature extremes."

Another thing to underline is the differences between white and red varieties. Aromatic white wines are usually present in cool climates because the aromas present develop more favorably (Duchêne et al. (2005)). Some studies identify those higher temperatures convey lower aromatic contents with the same sugar concentrations. Two primary sources are Belancic et al. (1997) and Reynolds et al. (1993)). These studies analyze aromatic and semi-aromatic varieties. Thus, one of the main qualities of these varieties is directly affected by increased temperatures.

Source	**Effect on grapes**	**Effect on wine quality**
Higher temperatures	Less acidity Higher sugar concentration Loss of anthocyanins Chemical modification of the compound	Less longevity Higher alcohol Color modification Lower aromatic contents
Excessive Heat	Chemical modification of compounds Loss of anthocyanins	Unbalanced wine/varietal flavors modification Color change
Wildfires	Smoke taint	Unpleasant flavors

Table 8*: Major impacts of global warming on grapes and consequences on wine quality. Source: personal contribution, Mira de Orduna (2010), Tarara et al. (2008), Sadras et al. (2012), and Howell (2008).*

To conclude this section of the thesis that deals with the effects of climate change on the quality of wine production, we sum up the findings in Table 8, also adding the wildfires' quality impacts. Finally, we summarize the effects of the sources of quality changing identifying the effect on grapes and the consequent effects on wine quality.

2.2 Literature review of econometric analyses

After revising the main features of the wine sector related to climate change impacts, we now consider what has been done in the academic literature on the effects of climate change.

We will firstly discuss the result of the analysis from a macro perspective. We then discuss the challenges present in climate econometrics analysis. In the final part of this section, we move into a micro perspective specific to the thesis topic.

We start analyzing the works of Kalkuhl and Wenz (2018) and Nordhaus (2018). These works examined the effects of an increase in temperature on the GDP.

Kalkuhl and Wenz (2018) use an econometric approach to analyze this fundamental relation. In this study, the Gross Regional Product instead of GDP gives a more satisfactory spatial resolution of results. The study cannot find evidence for permanent growth rate impacts. However, it finds robust evidence that temperature changes considerably impact productivity levels. Otherwise, other similar research (i.e., Burke et al. 2015) find evidence of permanent growth rate impacts. Furthermore, the current literature could not clear the growth-vs.-level that is still ambiguous and different results could be derived from methodology issues.

Results cover impacts on labor productivity, land productivity, and capital depreciation while non-market damages and other indirect damages (i.e., sea-level rise consequences) are not captured. Namely, these types of studies, contrary to damage functions based on Impact Assessments Models[22], make estimates referring to the effect of historic climate variables (i.e., mean temperature variability) on GDP. Consequently, they do not cover the full assessment and could only help better understand specific impact channels (i.e., labor productivity, land productivity, and capital depreciation).

Nordhaus (2018), instead, analyzes the results of the DICE model. This model is based on IAM’s that are defined as:

[22] A definition is given on the next page citing Nordhaus (2018)

"Approaches that integrate knowledge from two or more domains into a single framework. These are sometimes theoretical but are increasingly involve computerized dynamic models of varying levels of complexity.[23]*"*

IAM's have positive features; they give a broader assessment of damages, providing a full spectrum of the impacts. However, their structure makes it difficult to analyze their reliability using standard econometrics tools. This is a problematic feature that is common with earth system models. Nordhaus (2018) underline the modifications these models have had through the years. The significant changes through the years come from revising the social cost of carbon (dimensions not captured by Kalkuhl and Wenz (2018)). Due to this, the damage projected for 2100 has been revised upwards by 60%. This significant revision signals that uncertainties could significantly modify future estimates, which causes a reliability issue for these models based on IAM's.
To understand the possible helpful tool to analyze climate change economic impacts is essential to list the challenges that arise when a standard econometric analysis is made. Therefore, a revision of all the methodological issues related to climate econometrics is done following Hsiang (2016); these issues will be discussed below. Firstly, when there is climate econometric analysis to be done, two main questions emerge:

1. *What climate variables should be used on a regression?* We can use average values and variances or other summary statistics in a study. These statistics could be of different types, i.e., time frame beyond a critical value (e.g., extreme heat days) or multiple dimensions events (e.g., wind and hail simultaneously). However, there is currently no exhaustive list of summary statistics that cause impacts on economic parameters.

2. *How long should be the time interval that defines "climate"?* Also in this case, there is no fair definition; it is arbitrary. In some studies, it was described as an average of 30 years (e.g., by IPCC AR, Pachauri et al., (2014))

Besides these two questions, there are other issues; some are manageable, while others are still not resolved. Again, Hsiang (2016) proposed a trade-off analysis between the

[23] Nordhaus (2018)

main research designs: cross-sectional approaches, time-series variation, and a hybrid form between the two called “long differences.”. These approaches have some issues, such as vulnerability to omitted variables bias. Moreover, critical issues may come from nonlinearities. Nonlinear effects and their estimation could be verified only if observations of the impacts are highly resolved both in space and time. Usually, however, data are aggregated to be consistent in spatial or time resolution (e.g., in Kalkuhl and Wenz (2018), climate data have a resolution of 0.5°x0.5° however they are aggregated to match the GRP resolution). Furthermore, nonlinearities arise from the extreme values of climate variables; if average climate variables are used (e.g., mean temperature), these non-linear relations may not be found.

There is existing literature on the nonlinear relation between temperatures and yields of some crops. Schlenker et al. (2009) analyze Corn, Soybean, and Cotton. The study detects nonlinear relations between temperature and the yields of the crops studied. More precisely, it finds that the yield decreases sharply for all three crops over a temperature threshold (this behavior can be seen in Figure 7). The study underlines that regarding the relations between temperature and yields*:*

“The process is understood to be quite complex and dynamic in nature and thus not easily estimated in a regression framework.”

They use all three approaches described before to detect the nonlinear behavior: time series, cross-sectional, and panel variation. The best predictor of yields is the frame of time in which temperatures are above the specific crop threshold, summed over the growing season period, i.e., if for corn the threshold temperature is 29°C, with a temperature of 31°C, the resulting value will be 2°C. Moreover, the variable explains roughly half of the variation in yield and is a much better predictor of yield if compared to average temperature. These crucial results demonstrate that using average temperature as a climate variable may not be optimal.

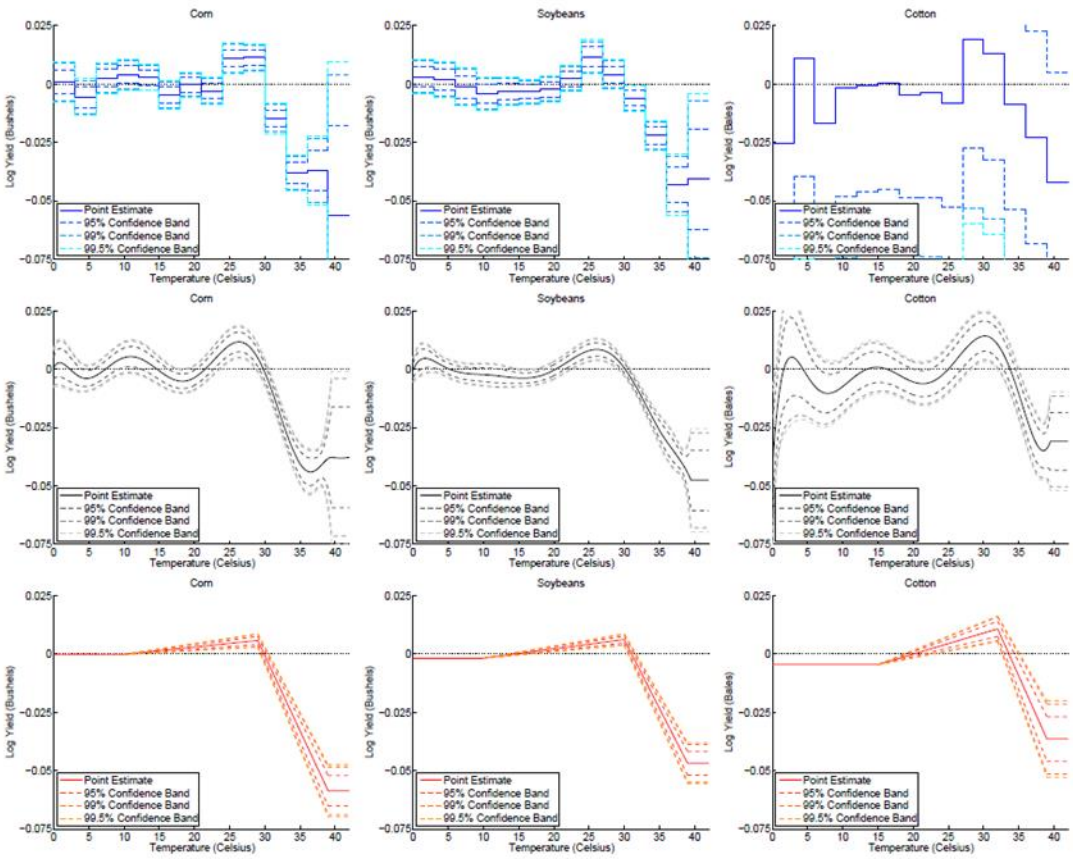

Figure 7: *Nonlinear relation between temperatures and crop yield. The figure describes three different models of specifications estimations on three different crops (corn, soybeans, and cotton). Source: Schlenker et al. (2009)*

To conclude the analysis of Hsiang (2016), we highlight three remaining challenges on climate econometrics:

1. The first is **matching effects and mechanisms**. As seen in Schlenker et al. (2009), impacts could be better captured if the correct climate variables are identified. Finding the chain of effects that from climate change leads to an impact is essential. Match effects and mechanisms could be done with integrated and multidisciplinary research.

2. The second challenge is related to **adaptation and general equilibrium**. The cost of adaptation is difficult to assess, but it will be economically significant. Usually, this cost cannot be captured because it is not already observed, but it should be

accounted for as one of the enormous costs of climate change. Moreover, assessments of the impacts are generally only partial and do not consider the indirect effects that could derive from the general equilibrium. This aspect is also essential in research on wine production and is highlighted both by Ashenfelter et al. (2014) and Sacchelli et al. (2016), already mentioned in paragraph 2.1.

3. The third is related to **unprecedented events**. If the climatic events are unprecedented, a model based on historical relations will difficultly capture the associated damages. In general, calibrating relations based on the past and projecting them on the future might be challenging if the conditions are changing, i.e., if the distribution of the climate variable used shift not only in the mean but also change the shape these relations are no longer valid (Woetzel et al. (2020))

These three points are essential when an analysis is made on the wine business. As we saw in the section related to the wine sector, the winemaking business is rich in peculiarities and complexities in its structure. Moreover, we see that the impacts of climate change are multidimensional, and the economic effects could be divided into two dimensions. Namely, climate change hit the revenues of a wine firm, decreasing the quantity produced and the quality of the wine produced. Therefore, it is essential to consider these two dimensions to assess the climate change impacts.

One standard way to analyze the impact of climate change on the wine business is to carry out an economic analysis of the events related to climate change and verify if it is possible to detect relations between climatic variables and variations on prices of equity of wine firms or variations on the cost of wine. Unfortunately, literature is scarce on this type of analysis, probably due to the challenges detected in the first part of this paragraph.

More precisely, we could not find any academic research regarding the study of equity prices variations of public wine companies caused by climate-related events.
If we investigate the reasons that may be behind this absence of academic literature regarding econometric analysis on equity price, we can state the followings points:

(1) Only a few wine companies are listed. Regarding Italian wine firms, there are only two listed companies in the Euronext Growth Milan: Italian Wine Brands (from 29/01/2015) and Masi Agricola (from 26/05/15).

(2) As mentioned in paragraph 2.1.1, there are different segments of the wine market; climate change will probably impact more on the high-quality parts of the market and in wineries with owned vineyards. Regarding Italian Wine Brand, it does not have owned vineyards or manage them; the group indeed buys the raw materials (both grapes and bulk wine) from other producers.

(3) Other Italian wineries are minor members of large groups listed as public companies. These groups have other productions or produce wine mainly in different parts of the world as core business. One example of a different core business is Campari, with wineries of Cinzano, Mondoro, and Riccadonna. Examples of international groups of wineries listed that also have Italian wineries are Constellation Brands (with Ruffino), Advini (La Collina Dei Ciliegi), Treasury Wine Estates (Cavaliere d'Oro, Stellina di Notte). There are various ways of coping with quality and quantity issues for these big, diversified groups of wineries. Regarding quantity reduction issues, they are limited through the location diversification of the production. Moreover, there are management techniques regarding quality issues like chemical addiction in the cellar. However, these ways to cope with climate change's effects on production quality could not be made for wineries that serve a high-quality market segment due to reputational issues.

Differently from climate econometric studies regarding equity price of Italian firms, some literature exists for other dimensions (e.g., bottle prices of wine). However, we could find some issues precedently identified in Hsiang (2016). Therefore, the studies analyzed are divided into different categories of issues.These are:

- **Omitted variables.**

  Chevet et al. (2011) analyze the prices and yields of Premier Cru Chateaux in the Bordeaux French region. The analysis covers the period from 1800 to 2009, and it finds a positive impact of temperature on both yields and prices. The average growing period temperature is used as a climate variable, as seen in this section averaging temperatures limits to detect nonlinearities present in the relations. Another possible issue is the omission of factors that could shape the relations between increased average temperature and growth in price. In the last thirty years, prices of Bordeaux wines have increased due to international success. The consequent increase in price determined by the increasing demand could be the primary driver of the rising prices.

- **Calibrate relations based on the past and project them in the future.**

  Ashenfelter and Storchmann (2010) make regression on wine prices and temperatures, finding different results when using auction retail and wholesale prices. In the study, he derives that (1) increases in temperatures result in increases in wine prices in every quality segment considered in the regression, and (2) increases in temperatures also have a positive effect on the quality of wines.

  The conclusions affirm that the wine revenues will increase more than proportionally with higher temperatures. So, they estimate that an upper temperature of 3◦C would more than double the value of the prices on the area considered, while an increase of 1°C would raise prices by about 30%. At the end of the discussion, it added that these conclusions could be applied for the Mosel Valley, but there could be places where an increase in the temperature will decrease the quality of the wine due to excessive heat. Ashenfelter and Storchmann (2010) is another study that follows an approach similar to the precedent paper done by the same authors. This study added a variable that describes solar radiation in the regression analysis. The area considered is always the Mosel valley, and the objective is to estimate the economic effect of climate change on the site. The results that can be cited are that "The estimates suggest that a temperature increase of 3°C results in profit increases of approximately 150%". This study disregards the possible nonlinear effects due to a further increase in temperature. If there was an increase in price related to the rise in temperatures, these relations could not necessarily be the same in the future. Moreover, there is probably an omitted variables issue. This issue can be seen in Figure 8. The increase in revenue (i.e., price of wine) is steeper in auction prices than in retail prices. This pattern could be associated with a higher increase in auction prices than other prices. Again, this is due to a higher demand for quality wine.

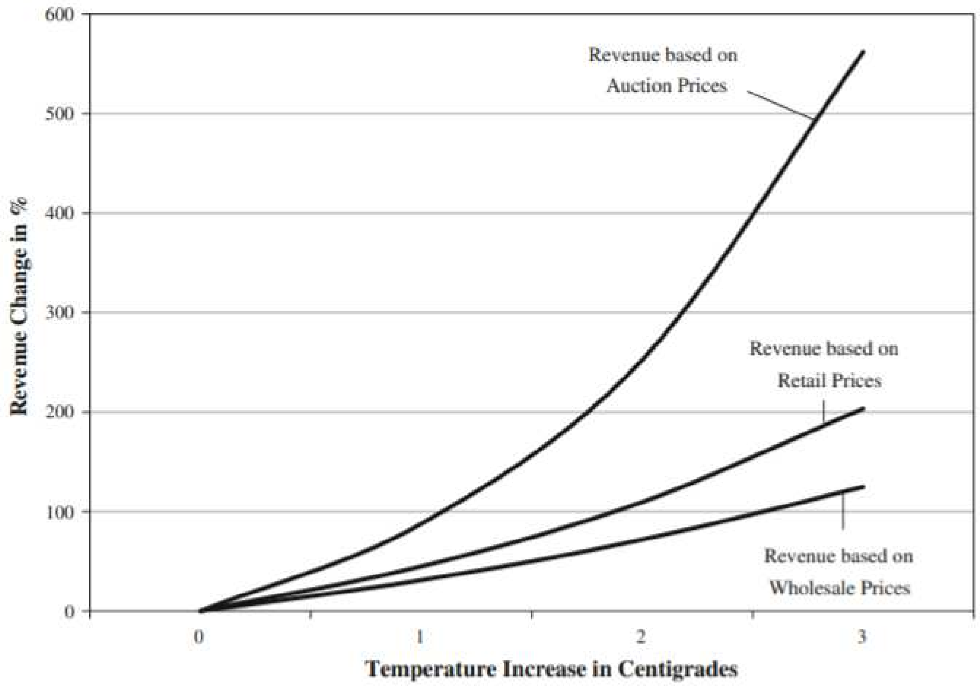

Figure 8: *the graph describes the relations between temperatures and the percentual change in wine prices. The relation is increasing. Omitted variables could cause the differences between auction prices, retail prices, and wholesale prices. Source: Ashenfelter and Storchmann (2010)*

De salvo et al. (2015) apply a spatial micro-econometric approach to estimate climate change impacts on the performance of wine firms in the Moldavian region. Results affirm that the Moldavian wine industry could benefit from climate change. According to the findings, there would be some losses only in a few locations but caused by increased precipitation and not by rising temperatures. The research analyzes the average expected change in temperature according to IPCC climate forecasts in the region. This change is expected to be approximately equal to 1 °C between 1986–2005 and 2020–2039. While for RCP 8.5, the temperature change is around two °C between the periods 1986–2005 and 2040–2059, and 3 °C between 1986–2005 and 2060–2079. The study estimates that the increase in temperature raises gross revenue. However, it employs a comparative static analysis in a long-run perspective, so this approach could not capture the dynamic transition between subsequent equilibrium states. Again, these relations are based on past results and projected in future scenarios; this could not be reliable if the shape of the distributions of the climate variable is continuously changing, as described in Figure 2 in paragraph 1.2.

To sum up the findings of this section, we highlight three main points related to econometric analysis related to climate change and wine production.

1. The relation between variations on wine prices (i.e., equity price and product price) and climate-related hazards is multidimensional and ambiguous. Moreover, there are various nonlinearities in these relations. We cannot expect that a standard econometric analysis could highlight these complex relations. This is supported by the small existing literature that usually has misleading results.

2. Calibrating relations between prices and temperatures or other climatic variables in the past and then projecting them in the future implies assuming non-modifications of the shape of the distribution of the climatic variables. However, this is not true, as seen in the first chapter (i.e., Figure 2) mentioning Woetzel et al. (2020). This is particularly the case when unprecedented events happen.

3. Climate change will impact different dimensions on wine firms' revenues. As seen in the previous paragraph, global warming impacts the quantity and quality of production, while extreme hazards may impact tangible assets. These dimensions are sources of non-linearities.

To better analyze the third point, a qualitative analysis of the main hazards that may affect the sector is done in the following paragraph. In this sense, a credit risk analysis is made. This analysis is valuable for at least qualitatively discussing some of these nonlinear aspects.
Instead, regarding the first two points, in the third chapter, we move from a backward-looking approach (i.e., econometric analysis) to a forward-looking approach, as suggested in Battiston (2019). In particular, in the final part of chapter 3, an empirical analysis based on an agroclimatic index is made comparing the historical values of this index to the projected values on two different pathways of emissions that coincide with two different scenarios of future physical risk.

2.3 Credit risk analysis

This paragraph aims to analyze the possible sources of credit risk deriving from climate change. In this sense, it is essential to understand if the creditworthiness of a winery will be modified due to climate change. Therefore, a qualitative analysis is conducted to assess if there are modifications on credit risk and investigate the sources of these modifications.

Some studies aim to identify how physical risk could impact credit risk. Faiella and Natoli (2018) deal with this topic in an Italian case study. This research will be used as a reference. Namely, they analyze the bank lending toward Italian firms exposed to the flood risk. They find that lending to non-financial firms is negatively correlated to flooding risk exposure. Moreover, this is mainly associated with small or medium firm borrowers. This insight is due to the more negligible capacity of diversification of small enterprises. The study uses a risk map of flooding in Italy and compares it with the Italian Central Credit Register dataset on bank loans. The study suggests that there might be an increased credit risk due to physical risk. This increase causes a decrease in credit availability. This fact could be easily extended to the sectors mainly exposed to other climate-related physical risks. These sectors may indeed suffer similar issues. As we saw in previous sections, the wine business is hugely exposed to damages related to climate change physical risk.

A borrower is usually considered creditworthy if it satisfies the 5 Cs of credit. These 5 Cs are Character, Capacity, Cash, Collateral, Conditions. Starting from these 5 Cs, climate change could modify some of them. Namely, it has some effects on **Cash** and **Collateral**. For example, changes in production capacity and product quality may alter the ability of the firm to generate cash flows. The modified cash flows will be derived from operations and generated from sales. On the other hand, there may be fluctuations in the prices of the assets usually placed as collateral for loans. One of these assets is vineyards (Cadot (2013)), whose value will be modified due to viticultural zoning relocation and consequent vineyard reallocation.
Due to the impairment in the creditworthiness positions of wine firms, as seen before, the consequence will be a decrease in lending activity and an increase in credit risk associated with loans towards the wine sector.

To analyze, in qualitative terms, the credit risk derived from climate change, we create a matrix that describes the possible impacts. This matrix is divided into two parts and is represented in Tables 9 and 10. All the dimensions identified will be described in this paragraph.

Hazard	**Type of hazard**	**Effects on Probability of Default**	**Effects on Recovery Rate**
Vine pests	Symmetric. Chronic.	Costs increase (pest control). Decrease in revenues (lower production).	Death of the vineyards.
Viticultural zoning relocation	Symmetric. Chronic.	Revenues decrease. (Lower profitability due to quality issue).	Decrease in the value of vineyards/land.
Heatwaves	Symmetric. Acute.	Revenues decrease (Lower profitability due to quality issue).	No impact.
Drought	Symmetric. Acute.	Revenues decrease. (Lower profitability due to lower production).	No impact.

Table 9*: symmetric hazards related to climate change. Impacts on the probability of default and recovery rate. Source: personal contribution*

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Hazard	Type of risk	Effects on Probability of Default	Effects on Recovery Rate
Wildfires	Asymmetric. Acute.	Revenues decrease. (Lower profitability due to smoke taint and quality issues, lower production for few years).	Limited cases of death of some vines. Damages to the winery.
Heavy rain/floods	Asymmetric. Acute.	Revenues decrease. (Lower profitability due to lower production).	Damages to the vineyards and winery.
Hail	Asymmetric. Acute.	Revenues decrease. (Lower profitability due to lower production for few years).	No impact.
Strong winds	Asymmetric. Acute.	Revenues decrease. (Lower profitability due to lower production).	Damages to the vineyards (uprooting).

Table 10*: asymmetric hazards related to climate change. Impacts on the probability of default and recovery rate. Source: personal contribution..*

We follow some steps to identify the features related to climate change impacts on credit risk. We first identify the potential climate hazards that could have implications for the financial position of a winemaking firm.

These climate-related hazards are extreme events that already impact wine production; we find eight main hazards already identified in the previous chapter. These hazards are:

- Wildfires
- Vine pests
- Viticultural zoning relocation

- Heatwaves
- Drought
- Heavy rain/floods
- Hail
- Strong winds

Some of these events are straightforward, like hail (Capitanio and De Pin (2018)) or vine pests; others are less associated as hazards for viticulture, but the last years confirms them as uprising threat for the wine production. An example is an extreme wind event that damaged some of the Valpolicella denomination in August 2020, with small portions of the hectares hit (only 5%) but with devastating consequences, up to the uprooting of the vineyards[24]. Another example is heavy rain and floods that hit the Ahr German region[25].

We analyze more precisely how these climate hazards may modify the financial position of wine firms and how they may increase the credit risk, where credit risk is the risk that a borrower will fail to meet the obligations in the agreed terms of the contract.

To analyze this type of risk is helpful to use two determinants of this risk, that are:

- Probability of default
- Recovery rate

The probability of default measures the likelihood of a firm that will go into bankruptcy in a given horizon of time. Obviously, it is also a benchmark for the probability that a firm will meet its debt obligations in a given period. Instead, the recovery rate is the part of the debt that will be given to the creditor given the debtor's default (so conditionally of this events). If the recovery rate is modified, also the expected amount of money that will return to the creditor if the debtor default is also modified.

[24] https://www.gamberorosso.it/notizie/notizie-vino/nubifragio-in-veneto-disastro-sfiorato-in-valpolicella-si-contano-i-danni-di-grandine-e-vento/
[25] https://www.winemag.com/2021/07/21/ahr-flood-germany-wine/

Regarding the recovery rate, the qualitative analysis that can be made is regarding the possible implications of climate change on the value of assets. For example, if a catastrophic event hits a winery, this could cause tangible assets value to decrease. Another real asset potential change is associated with the change in value on land/vineyards due to the relocation of viticultural zoning. This possibility is mainly concrete for viticultural areas with suited terroir features and so with high valuations of the land value deriving from the climate characteristics.
To make this analysis is also important to state if the hazard can be classified into one of the following categories:

- Asymmetric impact
- Symmetric impact

A hazard has an asymmetric impact if it covers a small area (i.e., hail) when it hits. It is asymmetric if when it hits, it produces damages on large areas (i.e., drought). This distinction can give insights into the possible risk management strategies that a firm can use to hedge this risk. These two concepts were already introduced in the risk management section. Insurance usually may cover only hazards with asymmetric impact. Taking apart the spatial impacts of a hazard introduced in the two previous categories, it is also essential to identify how the hazard has impacts in a temporal sense. Using the NGFS (2021) notation, we can divide the hazards related to physical risk into two categories of impacts. These categories are:

- Acute impacts: they come from weather events that are in the extreme of climate variables. These events can lead to business disruption and damages to tangible assets.

- Chronic impacts: they usually come from increasing temperatures. They have non-temporary consequences. These changes are generally associated with adaptation costs and consequent high need for investment to pursue adaptation.

While acute impacts may have catastrophic consequences every now and then, with an increasing probability of happening as long as climate change increases. Instead, chronic impacts are impacts that will be structural and will increase in magnitude while time passes. These two aspects pose the second type of risk to appear more imminent. However, both two types of risks must be accounted for. Moreover, in some cases, risk management techniques are adopted for chronic impacts due to their higher probability of these events and a consequent bias towards protection for a chance that is more probable with respect to seeking protection to an event less probable but with catastrophic consequences. This is due to miscalculations on the expected values of the two damages.

2.3.1 Resilience features of the sector

In paragraph 2.1.1, we introduce some features of the wine sector. These features give possibilities of adaptation to cope with weather variability. While grapevine is a fixed factor since it is a pluriannual crop, the wine produced has some flexibility instead. A wine firm could change some production processes to adapt to the annual weather conditions. More precisely, they could change the transformation period and the labels produced. The capacity to modify the transformation period and labels produced is a relevant resilience factor for the wine sector. In bad vintages with low-quality results, some labels may not reach the minimum quality to be bottled. The wine firms could, in this sense, decide to sell bulk wine or a lower quality label to decrease the income losses. These flexibilities in production have always been essential to cope with weather variability. They represent useful risk management tools on the farms level, and in some sense, with the correct management of these features, the risk decrease. Moreover, diversification in grapes varieties and sites of some of the Italian wine firms (Table 18 and Table 19 on the Appendix describes the wineries diversification in Antinori and Zonin1821) are indeed a risk management strategy to cope with not only weather variability but also market trends variability; these diversifications pursue hedge effects. However, it is difficult to state how much longer these adaptations that help cope with weather variability risks will be sufficient considering that climate change will continuously increase weather conditions variability, adding other unprecedented risks. However, concerning climate change, viticulture has developed in the last year different adaptation options. Nevertheless, these adaptations are difficult to be assessed. It is not easy to assess the trade-off between benefits and costs that these strategies imply (Sacchelli et al. (2017)). Different studies investigate these possible solutions to contrast the impacts of increasing temperatures and increase in extreme weather events. Some of these studies are summarized in van Leeuwen et al. (2019) and Santos et al. (2020). The adaptations strategies are divided into different solutions that may be acted in the short and in the long run.

Adaptation in the short run:

- **Crop cultural measures**: these comprise crop cultural practices and techniques that delay ripening stages to move the critical stages of the maturity of the grapes into cooler temperatures. The main practices are changes in canopy geometry, reduction of the assimilation surface of the plant through leaf removal above the cluster-zone, reduction of canopy size to minimize water consumption, usage of shadow nets, and, as seen in paragraph 2.1.2, an earlier harvested date to decrease sugar levels and increase acidity in grapes.

- **Protection against heatwaves**: sunscreen material application on the plants (e.g., calcium carbonate, kaolin, and potassium silicate) and shadow nets.

- **Irrigation**: also if in some Italian wine denominations, regulations (e.g., Brunello di Montalcino DOCG) are permitted only rescue irrigation. This is due to an increase in the yield and decrease in quality determined to an excess of irrigations

- **Pest and disease control**: to contrast the increase in vine pests already mentioned in paragraph 2.1.3.

- **Soil management**: practices to increase water management efficiency, and decrease erosion (e.g., cover crops)

Adaptation in the long run:

- **Changes in Training Systems**: some examples are minimal pruning systems, leaf area to fruit weight ratio changes, limitations of radiation in the cluster-zone through modifications of canopy geometry (i.e., row orientations, closer distances), vineyard orientation.

- **Varietal/clonal and rootstock selection**: changes in the varietal spectrum

- **Vineyard zoning relocation**: modifications in vineyard location (i.e., Shifts to cooler locations: higher latitudes or higher elevations)

Santillán et al. (2020) identify some critical points present on viticulture, which prevents some of these adaptation strategies. One aspect of complexity is the pluriannual nature of the grapevine, already discussed before in paragraph 2.1.1. When adaptation strategies that comprise a new plant are necessary (e.g., varietal cultivation modifications), this new plant needs five years to enter the production phase. Therefore, it does not give any cash flows on this timespan. Moreover, some adaptations can be made only on new vine plants. Modifications in plants would also have consequences on the terroir markup in prices (Elaydi et al. (2012) and Clingeleffer (2014)). The second aspect refers to the equilibrium of the vine culture. Management practices influence the quality of the wine even with slight modification. This influence is a weak point in the context of adaptation of vine cultivation if compared to other agricultural commodities. The third aspect can be found in the production labels choices. These are driven mainly by supply trends and, currently, is disregard the climate suitability of these production choices (e.g., cultivation of international varieties even if climatic conditions will make these weaken varieties exposed to climate change). Moreover, given that varieties choices are made long times before the production phase due to the pluriannual nature of vine (i.e., choice of new plant at year t gives production in year t+5 at least), the climatic conditions should be taken into consideration. However, recent market trends in Italy (i.e., substituting traditional grapevine varieties with Atlantic varieties such as Cabernet Sauvignon and Merlot more exposed to climate change and more water demanding) disregard the climatic factor this increase climate change risks.

To conclude this paragraph, we can state that the backward-looking decision-making process of wine firms is a limit for climate change adaptation that requires a forward-looking approach. This aspect could constitute an increase in risk not accounted for in this thesis. Research in this sense must guide this sector's future investments decision to prevent the most catastrophic consequences.

CHAPTER 3 - EMPIRICAL ANALYSIS OF AGROCLIMATIC INDEX IN TWENTY ITALIAN PRODUCTION AREAS

The previous chapter shows an econometric review of the research that analyzes climate change effects on GDP and wine business. This review concludes that an econometric model could not fully capture the impacts of a changing climate due to some complexities behind the chain of effects that starting from, i.e., a temperature distribution shift leads to an economic loss. Furthermore, a standard econometric analysis could have misleading results. We identify complexities both in the natural processes that lead to a change in climate (i.e., tipping points, nonlinear relations between higher temperatures and extreme events intensity) and in the profitability factor of the wine business (i.e., nonlinear links between temperatures variations and yields or quality/price variations). After the literature review, we make a qualitative credit risk analysis identifying the main hazards that could worsen the financial position of wine firms. This chapter introduces the need to move from a backward-looking perspective (i.e., econometrics analysis) to a forward-looking one (Battiston (2019)). Firstly, we present a way to price climate risk under uncertainty about future emissions pathways (Battiston et al. 2019). We then identify the challenges in applying this pricing method to the wine sector. To conclude, we shall move on to identify a possible risk assessment solution by analyzing an agroclimatic index widely used in the wine sector (Huglin Index) used as a risk metric. We make an empirical analysis of this index in twenty selected Italian production areas for two different representative concentration pathways (i.e., RCP 2.6 and 6.0). This Huglin Index analysis gives insights about one of the dimensions identified in the credit risk analysis, viticultural zoning relocation.

3.1 Framework for assessment of the economic shock related to climate change

In the first chapter, we describe how climate change, and more precisely, an unmitigated climate change that leads the world to a disorderly transition into a low-carbon economy, will change firms' revenues in different sectors. These changes in revenue will result in financial product values changes and consequential losses for investors[26] exposed to the industries/firms that will have negative impacts related to climate change.

Due to challenges in applying a standard econometric analysis, revised in paragraph 2.2, we need to change the perspective. A forward-looking approach (Battiston (2019)) should be followed instead of analyzing the relations between temperature variations and price or yield variations in a backward-looking perspective. Namely, we should start from the potential future revenues changes, building up a model that identifies the possible economic shock of each firm in a scenario of emissions. To execute this type of analysis, we need some assumptions. The first is that climate change directly modifies the revenues of some sectors of the economy; these direct consequences are the impacts underlying physical risk. Another part of sectors (i.e., carbon-intensive) will have problems related to the indirect result of climate change, namely, the difference in law/policy of emissions and the shift in future consumption trends to limit greenhouse gas emissions.
The second assumption is that consequent to the change in revenues, the values of the financial products (i.e., bonds or stocks of these firms) will be modified. Given the strict relations between future shock on the economy and emission pathways, it is crucial to analyze the future in different scenarios; each scenario needs to have an associated emission path and a consequent projected warming trend (i.e., higher temperatures, high probability of extreme events). Proxies of the possible shocks of the firms for every pathway of emissions (or scenarios) are finally identified through some models specifically for the sector considered, derived from IAM's.

This framework is taken from the approach used to pricing forward-looking climate risks under uncertainty suggested in Battiston et al. (2019). This approach was written for the assessment of the transition risks. Still, with some extensions and modifications, it can also be a valuable tool to study the climate change physical risk.

Battiston et al. (2019) firstly identify a set of climate policy scenarios Pl. Each scenario corresponds to a specific GHG emission reduction target. Scenario B (Business-as-Usual) refers to a scenario without changes in consumptions and output for the firms considered.

[26] Carney (2015)

[1]

$$ClimPolScen = [B; P_1; \dots; P_l; \dots; P_n]$$

Then as a second step, a set of economic output trajectories are identified. There is a different economic output for each country j, sector k, and under each scenario Pl identified in the previous step, estimated with a climate economic model Mm:

[2]

$$EconScen = [Y_{1,1,1,1}; \dots; Y_{j,k,Pl,Mm}; \dots]$$

As a third step, the forward-looking Climate Policy Shock Scenarios are built up as follow:

[3]

$$TranScen = [B \rightarrow P1; \dots; B \rightarrow Pl; \dots; B \rightarrow Pn]$$

In the final step, they identify a set of climate policy shocks on the economic outputs trajectories for each country j sector k and under transition scenario that goes from Business as usual to Pl estimated with the climate economic model Mm. Therefore, these shocks are the percentage difference of the economic output in a situation different from business as usual.

[4]

$$EconShock_{B \rightarrow Pl} = \frac{(Y_{j,k,Pl,Mm} - Y_{j,k,B,Mm})}{Y_{j,k,B,Mm}}$$

This framework is a good starting point, but changes to fit the wine sector characteristics are necessary. It should also be calibrated to capture physical risk impact.

Firstly, the climate policy scenarios should be the representative concentration pathways because these trajectories are the references mainly used in climate change models.

For example, we can take two emissions pathways to create a simple model. We decide to use RCP 2.6 for a best-case scenario and RCP 6.0 for a worst-case scenario.
In the model for assessing the climate change risks, we expect that there could be a positive or negative shock like the one described for transition risks.
To sum up and simplify: for regions with a cool climate, we expect a positive shock, while for areas with an already warm environment, we expect a negative shock. In general, we can assume that there will be a threshold point of temperatures, both medium and maximum, that when reached, will shift the positive effects of climate change into a negative one. This will turn the equivalent positive revenues shock into a negative one.
If we consider a model that describes the output of an agricultural firm, we must also make some assumptions about the proxy used to refer to revenue changes. The straightforward proxy that could be used is the yield of the agricultural product. The percentual difference between the projected yield and current yield will result in the projected yield shock:

[5]

$$YieldShock = \frac{projYield - currentYield}{currentYield}$$

Namely, in our model, there will be two possible scenarios (RCP 2.6, RCP 6.0), so for every location, there will be two potential yield shocks:

[6]

$$Yield\ shock\ 2.6\ = \frac{(\ 2.6Yield - \ actualYield)}{actualYield}$$

$$Yield\ shock\ 6.0\ = \frac{(\ 6.0Yield - \ actualYield)}{actualYield}$$

The following step will equivalate this shock on yield to the future shock on revenues.
Revenues will be divided into the different locations where these revenues are created. This is necessary to make a more precise analysis of the impact as there will be spatial variability on impacts related to climate change. Revenues will be split into the

different locations where those revenues come from. Therefore, we assume that there will be a distinct change in the climate conditions for each site and that these two main determinants will contribute to modifying the yield.

Example: a wine producer with 2 locations (loc1, loc 2) where 70% of the total production is in the first location and the other 30% is in the second location.

[Location 1]

$$Yieldshock2.6loc1 = \frac{2.6Yieldloc1 - currentYield}{actualYield}$$

$$Yieldshock6.0loc1 = \frac{6.0Yieldloc1 - currentYield}{actualYield}$$

[Location 2]

$$Yieldshock2.6loc2 = \frac{2.6Yieldloc2 - currentYield}{actualYield}$$

$$Yieldshock6.0loc2 = \frac{6.0Yieldloc2 - currentYield}{actualYield}$$

[Total shock in the two scenarios]

$$Scenario\ 2.6{:}\ TotalShock = 0.7\ x\ (2.6Yieldloc1) + 0.3\ x\ (2.6Yieldloc2)$$

$$Scenario\ 6.0{:}\ TotalShock = 0.7\ x\ (6.0Yieldloc1) + 0.3\ x\ (6.0Yieldloc2)$$

The proxies of the percentage of revenues deriving from each location need to be identified. There are different solutions to overcome this issue: the first possible way is to look if these data are disclosed. The second possible solution is to make assumptions regarding the hectares of each winery and divide them into the different locations where these hectares are located. Finally, another possibility is to make assumptions regarding the bottle produced by each winery. These assumptions, however, have some limitations; these limitations will be seen more deeply in the next section of paragraph 3.2.

After discussing the proxies to divide the revenues from each location, we must deal with some assumptions underlying the model to make the change in yield consistent with the change in revenues and compare the shock in yield to the shock on revenues.
The model does not consider adaptation strategies or technological changes that could derive from the research in the timespan between the current yield production and the future projected yield. As described in paragraph 2.3.1 of the previous chapter, there are many possible adaptation strategies, both in the short and in the long run. However, the model assumes that none of these strategies are adopted since it could not capture the dynamic nature of these adaptation strategies.
Another discussion needed is related to the comparison between yield and revenues. The assumption that a yield shock could be compared to the shock in revenues is consistent only if prices of wine will remain constant through time. This big assumption is in contrast with two considerations:

1. The first is the supply modification deriving from the changing yield patterns on the different production regions, positive in the cool region and negative in the warmer region.

2. The second factor is the possible price changes due to the quality modification and the price markup related to terroir (Elaydi et al. (2012)) that could be lost due to zoning modifications.

As seen before, not all varietals of grapes have the same behavior and response to climatic conditions. Each variety has a specific climate condition optimum. This aspect should be considered when an analysis is made. Consequently, our model captures only location; it should also consider the grape variety. Therefore, we insert in the function of the yield shock not only the site of the vineyards but also the grape variety.

[7]

$$Yieldshock = Yield\ (location, Grape\ variety)$$

Adding the variable of grapes variety makes the model more complex; therefore, not considering this variable would cause some wrong interpretation and would hide the diversities on the Italian wine regions and the advantage of some wineries due to the grape varieties chosen for the production. However, even if it is well known that grapes varieties are different in terms of adaptation to climate change, there is no methodology to implement such types of variables on a model. The following paragraph will discuss the main challenges that limit the application of the model discussed in this section to the wine sector.

3.2 Challenges in applying analysis to the wine sector

It is possible to depict some issues related to implementing the model described in the previous paragraph to assess the possible shock, given a specific emission pathway.

The first challenge, and the most essential, is related to the **output model for wine grapes yield**. Isimip gives output data regarding different agricultural products. These dataset are used in some studies, e.g., Rosenzweig et al. (2014) and Hristov et al. (2020). These crops are the more extended and strategic for food security (i.e., wheat, maize, soy, rice). While there exists some projection for future output for these cultures, these data are not present for wine grapes. This lack of data is a significant limitation for the analysis, as there cannot be proxies to analyze the possible yield shock in the production.
Moreover, wine is obtained after a transformation from raw agricultural products to another product; this gives, as we already highlighted, a source of complexity. Usually, agricultural production profitability depends mainly on the yield, so it is simply to say that the correct proxy for revenue shock could be the yield shock. However, this assumption could not stand for wine firms as profitability depends on other critical variables, as we have already seen before. Namely, we can affirm that the worsening quality of the production could be more harmful than the decrease in yield for the profitability of some wineries (e.g., high-quality ones). This aspect raises some doubts also concerning the assumption of **fixed prices**. A change in climate with all the consequences we have seen in this thesis will indeed modify the prices. Namely, a model that calibrates the economic shock based only on quantity changes would not be helpful to capture the actual shock. Moreover, the results will be misleading. Again, there is necessary to consider the general equilibrium and not only partial a concept already presented in paragraph 2.2.

Another challenge is related to what we described before and tied with wine yield and quality. There is indeed an ambiguity specific to the wine grapes crop. Unlike other agricultural products, a decrease in production quantity is not inevitably associated with an economic loss. As seen in this thesis, the yield of a harvest is one of the first indicators of wine quality. So, a small yield is considered a good signal of the absolute quality differently from other agricultural commodities. Again, if we consider all these specific features, the assumption to take as a proxy of the financial shock deriving from climate change equal to the shock in production quantity (yield shock) is no longer meaningful.

The third challenge is related to the wine sector and **data disclosure**. It is challenging to find an alternative proxy to substitute the yield related to the wine yield ambiguity described before. However, a proxy of revenues in the wine sector could be derived with a simple formula:

[8]

$$Revenues \approx price\ of\ bottle \times quantity\ of\ bottles\ sold$$

As we saw in paragraph 2.1.1, a winemaker typically produces different bottle lines to obtain label diversification. So, to get a proxy of the revenues for each location, we should know the number of bottles sold and the price of the bottle every single label produced. Therefore, we should consider the price that the firms apply and not the market price. In this sense, it is clear that there are a market and a secondary wine market (Masset et al. (2022)). Usually, we know the price related to the secondary market that serves the final customer, while the price described in equation 8 is related to the primary market.

However, the firms do not disclose these two essential quantities: the price of the bottle and the amount of bottle sold each year. This lack of disclosures is a significant limit for future projections of the revenues with climate change and for assessing past impacts of weather extremes on the revenues of wine firms. Namely, a backward analysis on specific outliner vintage deriving from extreme climate seasons could be helpful to understand how future climate change may impact.

3.3 Agroclimatic index measures of risk

The model proposed in the first section of this chapter has some challenges described in the second paragraph. Some of these challenges have no solution (e.g., the problem related to the lack of an output model of wine grapes). Another approach will be given in this paragraph to overcome the issues found.

The objective is to continue the forward-looking approach. Looking at the literature about climate change and wine, some authors try to model climate change impacts using agroclimatic indexes. More precisely, they use projections of future temperatures to calculate projected agroclimatic indicators in a future emission scenario. They then compare the projected indicator with the historical one. The shift between historical and projected values of these indicators could give insights into the risks involved and future adaptation needs for each location. They could also underline the differences, if any, of climate change in a spatial sense. This approach has been considered adequate to give an impact assessment of climate change on a local scale. Different studies state this (e.g., Santillán et al. (2020), Tonietto and Carbonneau (2004), Moriondo et al. (2011)). One of these studies (Santillán et al. (2020)) will be described briefly to provide insights into the methodology adopted. The shift in the values of agroclimatic indexes between a baseline historical period and a future projected period with an RCP could quantify how much change in climate is expected to be in a location. Therefore, it is possible to affirm that the economic loss of wine firms due to climate change will be directly proportional to the increase of these indicators. However, it does not indicate the magnitude of these effects due to the complex relations behind the dynamics of climate change and the consequent economic losses.

Santillán et al. (2020) use some indicators (HI, CNI, SPEI described in Table 11) that are used widely to offer information on wine grape culture, associating the change of these indicators, in a consistent set of climate change scenarios, as a risk measure for future adaptation needs of the area subject to these projected changes of these index of production suitability.

Expression	Category name	Range
$HI = \sum_{i=Dini}^{Dend} \frac{(T_i - 10) + (T_{max,i} - 10)}{2} d$ where Dini is the starting date, 1 April; Dend is the ending date, 30 September; T_i is the average daily temperature in Celsius degrees (°C); $T_{max, i}$ is the maximum daily temperature in °C; and d is a coefficient that depends on the day length	Very warm	HI > 3000°C
	Warm	2400 °C < HI ≤ 3000 °C
	Temperate warm	2100 °C < HI ≤ 2400 °C
	Temperate	1800 °C < HI ≤ 2100 °C
	Cool	1500 °C < HI ≤ 1800 °C
	Very Cool	HI ≤ 1500 °C
CNI = minimum air temperature in °C in September	Very cool nights	CNI ≤ 12 °C
	Cool nignt	12 °C < °CNI ≤ 14 °C
	Temperate nights	14 °C < °CNI ≤ 18 °C
	Warm nights	CNI > 18 °C
SPEI is the standardized value of the probability distribution function of the monthly difference (D_i) series, defined as: $D_i = P_i - PET_i$	Very dry	SPEI ≤ −1.5
	Dry	−1.5 < SPEI ≤ −1.0
	Moderately dry	−1.0 < SPEI ≤ 0.0
	Sub-humid	0.0 < SPEI ≤ 1.0
	Humid	1.0 < SPEI ≤ 1.5
	Very humid	SPEI > 1.5

Table 11: *Description of the three indexes used in Santillán et al. (2020), with the related interval for climate categories. Source: Santillán et al. (2020)*

The study investigates the spatial distribution of the degree of damages caused by climate change. The scenarios used for climate change are the representative concentration pathways, and they are derived from global datasets. Adaptation needs are divided into three categories (low, medium, high) proportionally to the chosen index change. The change in the index is not the absolute change with a medium historical value. Instead, it is the shift from different categories individuated for each index and described in Table 11.

Adaptation efforts are constructed with some specific criteria, based on the shift from one index category to another. Namely, they divided changes into four categories:

- No adaptation needs. The three indexes do not change between the initial and projected future indexes categories. The temperature index change from very cold to cold, and the drought index change only from very humid to humid. In the map, these areas are colored green.
- Low adaptation needs. HI may change only until temperate warm, for example, from cool to temperate or temperate warm, or from temperate to temperate warm.

CNI, instead, may vary from very cool to cool. SPEI may change only until moderately dry. In the map, these areas are colored in yellow.

- Medium adaptation needs. This is when the HI index changes until warm. In the case of the CNI, it should change until temperate. For the SPEI, the categories may vary from very humid to moderately dry, from humid sub-humid, or moderately dry to dry. In the map, these areas are colored in orange
- High adaptation needs. This is when HI and CNI reach the higher temperature and drought category while the SPEI index goes dry. In the map, these areas are colored in red.

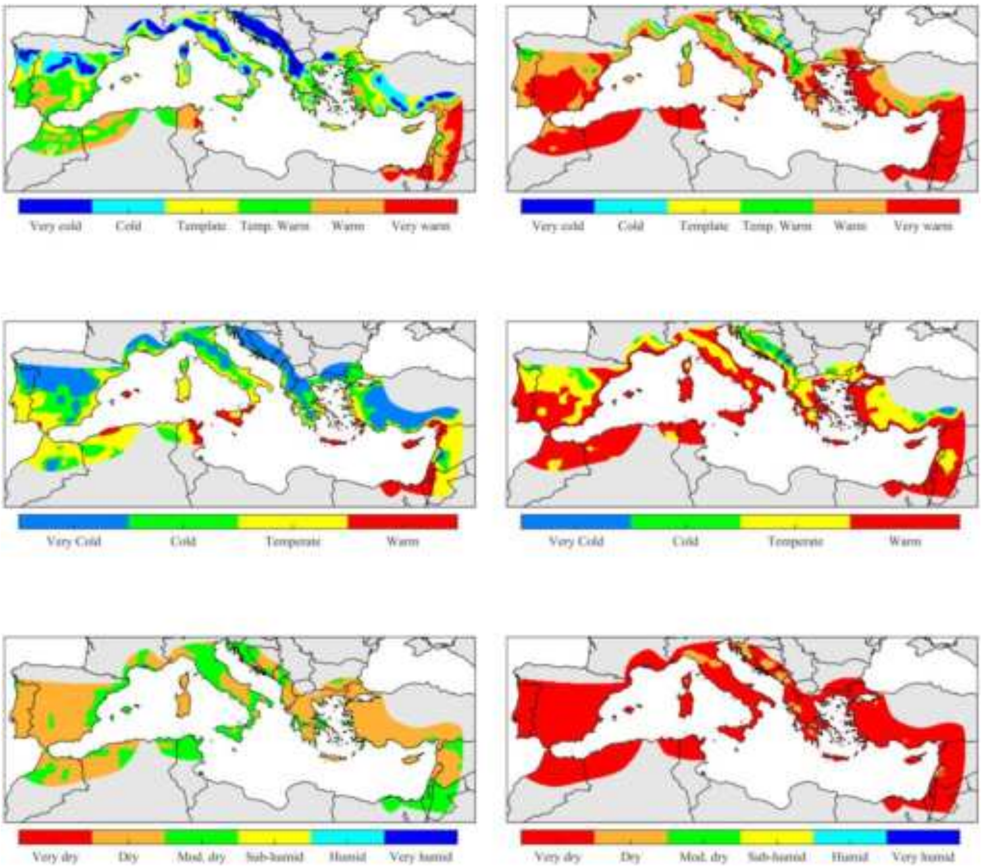

Figure 9: *in the figure, there is a description of the change in the index category through time. In the left part, there are the categories in 1951, while on the right, there are the projected categories on an RCP 6.0 in 2099. From the top to down, the indexes described are Huglin Index, Cool Night Index, and SPEI. Source: Santillán et al. (2020)*

3.3.1 Huglin Index

In the previous paragraph, we introduce, employing a literature review, an approach for assessing climate change impacts based on agroclimatic indicators. This thesis will concentrate on the Huglin Index analysis, already introduced in the previous paragraph, because it was used in Santillán et al. (2020), one of the primary references for this type of approach.

[9]

$$Huglin\ Index = \sum_{Apr1}^{Sep30} max\left\{\frac{[(T_{mean} - 10) + (T_{max} - 10)]}{2}, 0\right\} \times K$$

Where K is described in Table 12.

K coefficient value (Vaudour (2003))	**Latitude**
K=1.00	from 36° 1’ to 38° 0’
K=1.01	from 38° 1’ to 40° 0’
K=1.02	from 40° 1’ to 42° 0’
K=1.03	from 42° 1’ to 44° 0’
K=1.04	from 44° 1’ to 46° 0’

Table 12: *description of the day lengths coefficient in the Huglin Index with latitude values. Source: Vaudour (2003).*

The Huglin Index is calculated summing up the maximum daily temperature and the minimum daily temperature over the threshold of 10 °C in the period that goes from the first of April to the thirty-first of September. This index is useful because it covers all the ripening periods of grapes and, differently from other similar indexes (e.g., Winkler Index, Growing Degree Days), incorporates in the formulation also the variable K. This coefficient is a proxy for the day length and so the potential amount of light that the vineyard obtains during the day. Furthermore, K depends on the latitude, and so it gives a differentiation of the index based on the location of the vineyards object of the analysis. Huglin created this index in 1978 after several tests on Winkler and Brana's indexes. It was used an ampelographic collection of the agronomic station of the French agronomic institute in Colmar. Huglin Index calculations on a six-month period resulted in being more correlated with the sugar content of hundreds of varieties if compared with other indexes (Vaudour, 2003). Table 13 describes the ranges of the Huglin Index values for each grape variety related to the sugar content of 180/200 g/l according to the Huglin experiment in 1978.

Huglin Index (Huglin 1978)	**Grape Variety**
$1500 \leq H < 1600$	Müller-Thurgau, Blauer Portugieser
$1600 \leq H < 1700$	Pinot blanc, Grauer Burgunder, Aligoté, Gamay noir, Gewürztraminer
$1700 \leq H < 1800$	Riesling, Chardonnay, Silvaner, Sauvignon blanc, Pinot noir, Grüner Veltliner
$1800 \leq H < 1900$	Cabernet Franc
$1900 \leq H < 2000$	Chenin blanc, Cabernet Sauvignon, Merlot, Sémillon, Welschriesling
$2000 \leq H < 2100$	Ugni blanc
$2100 \leq H < 2200$	Grenache, Syrah, Cinsaut
$2200 \leq H < 2300$	Carignan
$2300 \leq H < 2400$	Aramon

Table 13: *range of values for grape varieties according to Huglin Index experiment for sugar content of 180/200 g/l Source: Huglin (1978)*

As mentioned before, integrated into the Huglin formula, there are both mean and maximum temperatures. Namely, maximum temperatures differentiate vineyards with similar mean temperatures but different viticultural features due to other daily temperature fluctuations. To sum up:

- The Huglin Index (HI) provides information about the temperature suitability of the plant. This index assesses the ability of varieties' suitability in a specific wine region. There is widespread acceptance and use of this index in particular in Europe.

- Huglin Index is helpful to divide areas into different climate regions. There is also an upper (3000) and lower (1200) limit for wine production (Huglin (1978), Tonietto and Carbonneau (2004), Jones et al. (2010)).

Through Huglin index indications, such as grape variety suitability and climatic region, we can state that Huglin Index is helpful for studying the viticultural zoning relocation. This is one of the hazards studied in paragraph 2.3 in our credit risk analysis. Therefore, we could derive different assumptions:

- One is simply that a specific index range coincides with a balanced wine produced for every grape variety. We could also consider this range the optimum for production profitability. So, we can assume that for every grape variety, there is a range of index values where these varieties give their best quantity and quality.

- While the ranges determined on the research of Huglin cannot be used to specifically isolate the place where a specific grape variety should grow because of other factors that could alter the values found in the past (e.g., vineyard technique adopted and growing practice), maximum and mean temperatures could not indeed explain all the potential suitability of a variety. However, the ranges of grape varieties give insights into the suitability equilibrium.

- One crucial aspect is that small steps on the index (i.e., 100 units) could determine the shift from one variety to another (e.g., the change in the optimal sugar content). This is an attestation to the well-known fact that viticulture must have specific climate conditions and the importance of selecting specific varieties to have the best results given the cultivation location. This notion is well translated into the concept of terroir. In our analysis, a shift from mean historical values coincides with increased physical risk due to the increased probability of viticultural zoning relocation.

3.3.2 Dataset

The raw data derives from the Copernicus dataset[27]. The variables used are:

- Mean of daily mean temperature on ten days expressed in Kelvin (TG).
- Mean of daily maximum temperature on ten days expressed in Kelvin (TX).

The Copernicus dataset gives the temperatures with a temporal aggregation (the period over which the data are averaged) of dekad (e.g., ten-day period). The dekads in the dataset start from the first of the month to the tenth, then from the eleventh to the twenty-first, and the last from the twenty-first to the end of the month. In this sense, the raw data (TG, TX) is the ten days mean of daily mean and maximum temperature from the start of April to the end of September. Copernicus gives different data sources. We use data derived from the IPSL-CM5A-LR Model (IPSL, France) in our analysis.

The dataset gives a 30-years period for the historical data and the projections. The data are so divided into different files with a 30-year period. The whole frame of time covered goes from January 1951 to December 2099.

Data experiments are the result of specific Representative concentration pathways, while historical data are used in the period from 1951 to 2011. The dataset is based on ISIMIP fast track data. ISIMIP provides the actual runs, not ensemble means or means over realizations. Hence, projected data are single realizations of a climate model. The difference is relevant because it could have much lower variability over time if the future trajectory is an average. Furthermore, it may also be incorrect to glue past trajectories (which represent a single realization, i.e., the observed one) with a future projection that

[27] https://cds.climate.copernicus.eu/cdsapp#!/dataset/sis-agroclimatic-indicators?tab=overview

is the mean of more realizations. Namely, this would cause issues when comparing past trajectories to future ones.

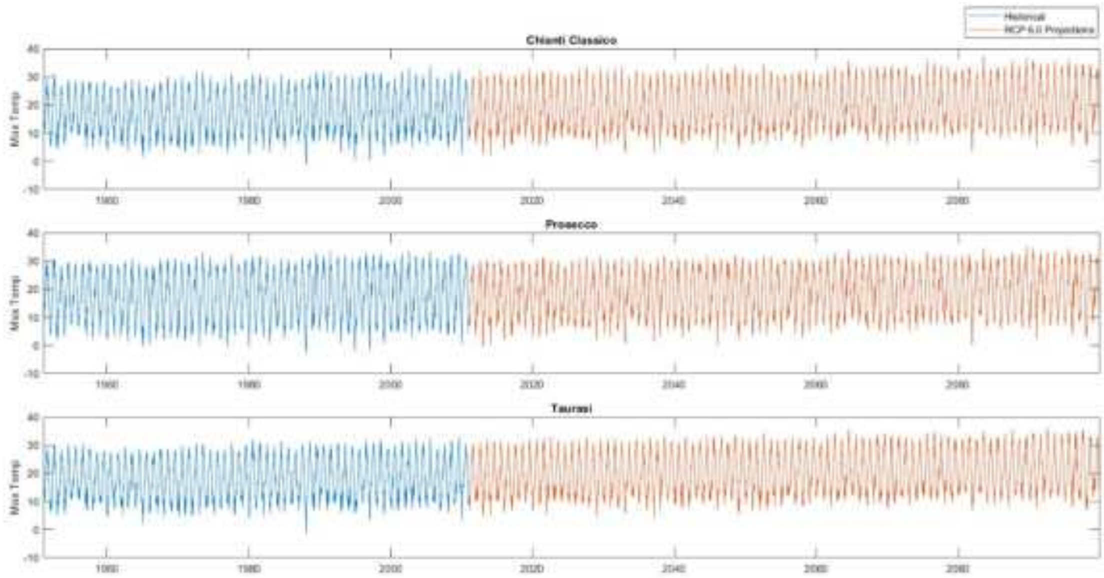

Figure 10: *raw data representation. Maximum temperatures from 1951 to 2099 in three areas (Chianti DOCG, Prosecco DOCG, and Taurasi DOCG). The Blue part represents historical values while, the red part represents projection on RCP 6.0. Source: personal contribution of Copernicus data.*

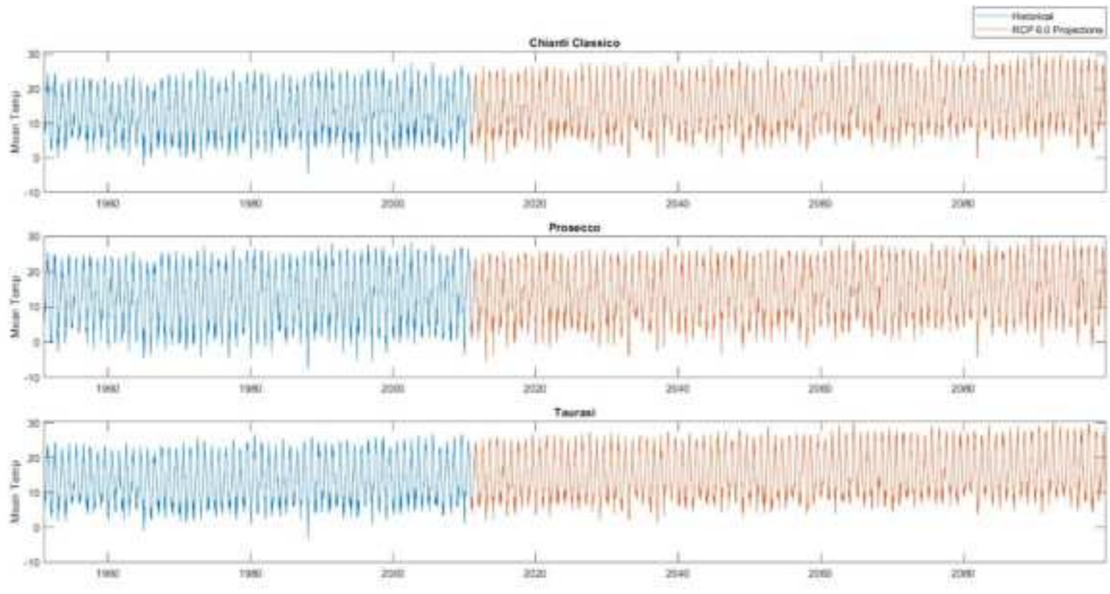

Figure 11: *raw data representation. Mean temperatures from 1951 to 2099 in three areas (Chianti DOCG, Prosecco DOCG, and Taurasi DOCG). The blue parts represent historical values while, the red parts represent projection on RCP 6.0. Source: personal contribution of Copernicus data.*

Figures 12 and 13 describe the raw data, i.e., the maximum and mean daily temperature mean over ten days, for three selected areas (i.e., Chianti Classico, Prosecco, Taurasi)[28]. From the figures, we can state that the trend through the years is increasing, and it is clear both in mean and maximum temperatures. This projection of a growing trend is due to global warming; the pathway of emissions used in the figures is RCP 6.0, and so is the most extreme of the two paths selected for this analysis. The blue parts describe historical data from 1951 to 2011, while the red parts show the projected temperatures from 2011 to 2099. Moreover, raw data does not give us much more information than the temperature's upward trend; in this sense, data needs to be transformed.

As seen, the Copernicus dataset provides some historical and projected future data. Namely, the ten days mean values of the maximum and mean daily temperature are provided. Therefore, on the Huglin Index formula, there are instead the daily maximum and mean temperatures.
However, the formula is the sum of the daily values, so we can use the mean on ten days multiplied by ten to obtain the sum of ten days' daily mean or maximum temperature.

[10]

$$\sum_1^{10}(TMean_{day1}, \dots, TMean_{day10}) = Mean\ (TMean_{day1} + \cdots + TMean_{day10})\ x\ 10$$

[11]

$$(TMean_{day10} + \cdots + TMean_{day10})\ = \frac{1}{10}\sum_{1}^{10}(TMean_{day1} + \cdots + TMean_{day10})\ x\ 10$$

This important feature of the Huglin Index makes the Copernicus dataset usable. Without this feature, the data used in the formula and temperatures ten-days mean of the dataset would be inconsistent. This could be an issue if the maximum temperatures given by the

[28] More on the description of the selected area will be seen at the end of this section, a summarized representation is in Figure 12.

dataset were the maximum temperature of the ten days and not the ten-day mean of the daily maximum temperature, but this is not the case.

However, this type of dataset could cause slight changes in the Index. For example, the Huglin index considers a daily value only if it exceeds 10 °C (e.g., if mean and maximum temperature minus ten gives a negative value, this is rejected). Some days could have the mean (or maximum) temperature on the ten days higher than the threshold, while on these ten daily values, there could be some values that do not reach the threshold, so that should not be considered. This issue, however, could slightly change the values of the Index. It can overestimate or underestimate the result. To overcome this issue and be consistent, the part of the formulation that considers only the maximum value between 0 and the temperature (maximum or mean) minus ten is not considered. It is considered instead only the temperatures minus ten. This could cause a lower value in the index of cooler locations, while it has little or no effects on warmer areas. In this sense, we operate a conservative approximation.

More precisely, to sum up, the formulation used to transform raw data into yearly Huglin Index is this:

[12]

$$Huglin\ Index = \sum_{Apr1}^{Sep30} \frac{[(TDekad_{mean} - 10)\ + (TDekad_{max} - 10)]}{2} \times K \times 10$$

$TDekad_{mean} = ten\ days\ period\ mean\ of\ daily\ mean\ temperature$
$TDekad_{max} = ten\ days\ period\ mean\ of\ daily\ maximum\ temperature$
$K = days\ lenght\ defined\ in\ Table\ 13$

To extract and calculate the index, MATLAB was used. The dataset was on the ".NC" file extension, and we used MATLAB scripts to transform data. More precisely we:

- Extract from the global dataset the data of a single location, both maximum and mean temperatures ten-days mean, that were on two separated series.
- Remove temperatures on the months not considered into the Huglin Index formula, so in the period that goes from October to March, to obtain the data only on the correct April-September period.
- Transform data from Kelvin to Celsius.
- Implements the formula of the Huglin Index and for every year associate a value of the Huglin Index

This process is made firstly for the historical period series, and then for the projected period; firstly, for the series regarding RCP 2.6 and then for the series relating to RCP 6.0

After describing the derivation of the raw data of the Huglin index, we now describe the spatial representation of the analysis. Copernicus Dataset is a global dataset. It uses the Isimip Fast Track, and the planet earth is divided into a grid of 0.5° x 0.5°; this division gives us resulting temperatures for every grid. These spatial data resolutions allow us to calculate the Huglin Index for every 0.5° x 0.5° land portion area. Therefore, we can focus our analysis only on the most suited viticultural Italian area.
The locations chosen for the analysis covers a vast part of the viticultural area of Italy. Table 20 in the Appendix describes the sites in the center of the square areas considered in our analysis with latitude and longitude. Moreover, the municipalities are described together with the province and regions. Namely, these squares areas are identified with the name of specific viticultural regions as reported in Figure 12. However, a smaller resolution would be helpful to analyze more precisely distinct terroir. More precisely, this can be stated for small denominations such as the Bolgheri DOC area. Such example are described in Figure 24 in the Appendix. It is possible to visualize the high density of vineyards present in a restricted location, a portion of the land way smaller with respect to the 0.5° x 0.5° grids. This also gives an idea of how restricted some denominations could be and how a restricted area could have specific climatic and soil conditions that are not present in a land a few kilometers away. This is an issue of our analysis that does not have a solution unless a more acceptable spatial data resolution is given in the future. In our analysis, every portion of land analyzed is associated with a wine denomination, in order to simplify the collocation, even if in the same square portion there might be

more wine denominations (e.g., in Barolo DOCG portion there are also Barbaresco DOCG, however, only Barolo DOCG is reported to simplify). These denominations are also the reason why such locations are chosen. Moreover, the locations were chosen for the analysis to cover different characteristics:

- A group of 7 areas is taken from the principal “Italian terroir,” we select these areas due to the higher valuation of vineyards already discussed in paragraph 2.1.1. These are: Amarone DOCG, Prosecco DOCG, Barolo DOCG (that in our resolution of data coincides also with Barbaresco DOCG), Brunello di Montalcino DOCG, Nobile di Montepulciano DOCG, Bolgheri DOC and Etna DOC. We disregard the Alto Adige denomination due to the effects of altitudes on temperatures that are difficult to handle.

- Another group is chosen between the remaining Italian DOC and DOCG denominations. More precisely, one location in Piemonte (Barbera d’Asti DOCG) one in Friuli Venezia Giulia (Collio Goriziano DOC), one in Tuscany (Morellino di Scansano DOCG), two in Sicily (Marsala DOC, Cerasuolo di Vittoria DOCG), one in Abruzzo (Verdicchio DOCG), three in Campania (Fiano di Avellino DOCG, Greco di Tufo DOCG, Taurasi DOCG), one in Puglia (Primitivo di Manduria DOCG),

The locations chosen include ten of the Italian regions. These locations are also selected to distribute the analysis through different sites and critical areas (e.g., Sicily). As mentioned before, the Huglin Index for a location is, therefore, a spatial average. It is not a punctual measurement of a single place. Averaging over space could be an issue due to losing some of the data information (Hsiang (2016)). Take the average of temperatures and, more precisely, maximum temperatures over spatial or time could result in smoother results.

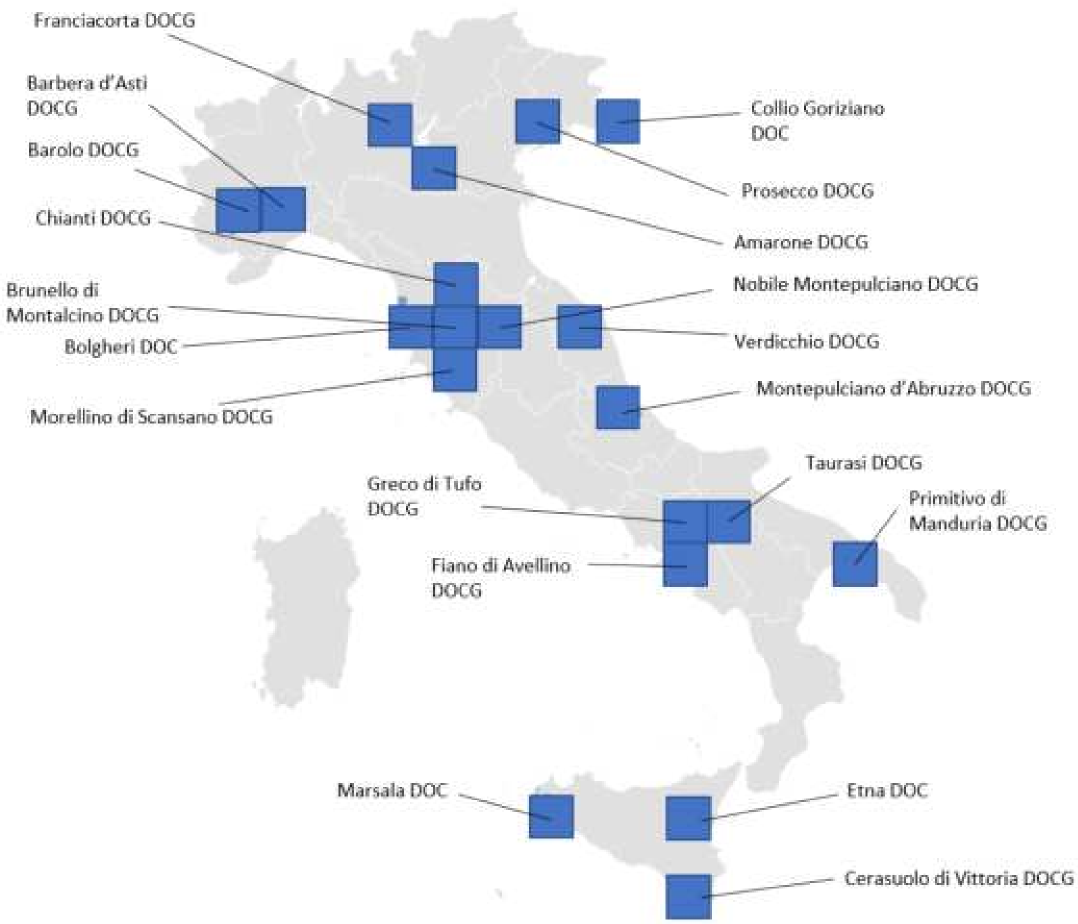

Figure 12: *Description of the twenty selected Italian areas. Each blue square represents the 0.5° x 0.5° land portion of the area covered by the index (i.e., average over space). In addition, at each area covered is assigned a wine denomination to give a reference.*

3.3.3 Results

In the previous sections, we describe the Huglin Index identifying the analysis we want to do to improve the approach of Sàntillan et al. (2020). Then we described the dataset used and how we transform data in the Huglin Index. Finally, in this paragraph, we describe the results found. All the results in this paragraph are personal contributions. Whenever in this section, we will use terms such as "*location*," "*region*," "*area*," followed by a wine denomination referring to the denomination chosen in the portion of the 0.5° x 0.5° identified in Figure 12 as described in the previous section, as stated before, we will refer not at the denomination itself but to the whole square portions highlighted in blue in Figure 12. This convention gives a simple and intuitive representation of the land portion.Figure 13 describes the time series from 1951 to 2099 with the calculated Huglin Index values of the twenty locations chosen.

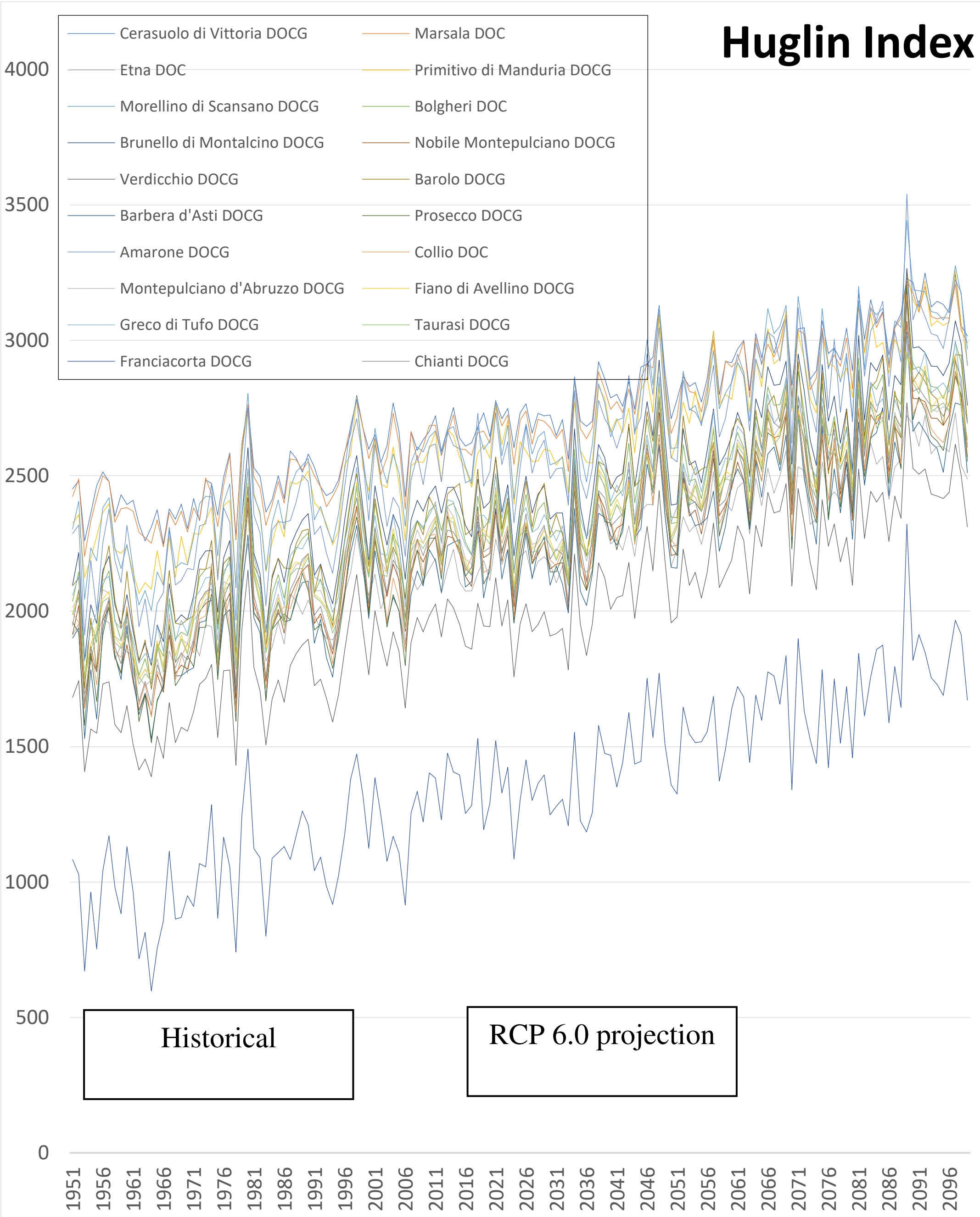

Figure 13: *Time series (1951-2099) with Huglin Index values on the twenty locations. The right part of (2011-2099) the index is calculated with RCP 6.0 temperatures values while the left part is calculated with historical values (1951-2010).*

In the left part of Figure 13, the index values are calculated with historical values, while in the right part, they are calculated with the projected temperatures of an RCP 6.0. This RCP is the worst scenario of emissions of the two considered in our analysis.

We could have some insights from this raw representation of the Huglin Index values. These could be sum up in some main points:

- There is an upward trend in all the twenty locations in the graph.
- This increasing trend could be seen both in the left (historical) and in the projected part.
- The increasing rate is much higher in the projected part than the historical part. Related to this, we can expect that future impacts on production will develop more rapidly than in the past.
- Already from this raw representation, we could derive that data referring to Franciacorta DOCG has some issues; this is probably due to different degrees of altitudes in the area considered.

All the calculated values of the Huglin Index are in the Appendix of this thesis. The table is divided into three parts. First, the historical period (1951-2010) is in Table 21. While the projected period (2011-2099) is divided into two tables, the RCP 2.6 projected values are on Table 23, while the RCP 6.0 projected values are on Table 24. Moreover, in Table 25, there are differences between RCP 6.0 and RCP 2.6.

Figure 14 describes instead only the historical data. The higher value in the historical period is 2803 associated with the Morellino di Scansano DOCG area in 1980, while the lowest value is 597 associated with Franciacorta in 1964. This lowest value confirms the altitudes issue referring to the Franciacorta DOCG area. All the values of this area are far lower than all the other areas. Considering all the historical periods, the Franciacorta area has a mean value of 1063. The second-lowest mean site is the Verdicchio Docg that therefore has a value of 658 units higher than the Franciacorta DOCG one.

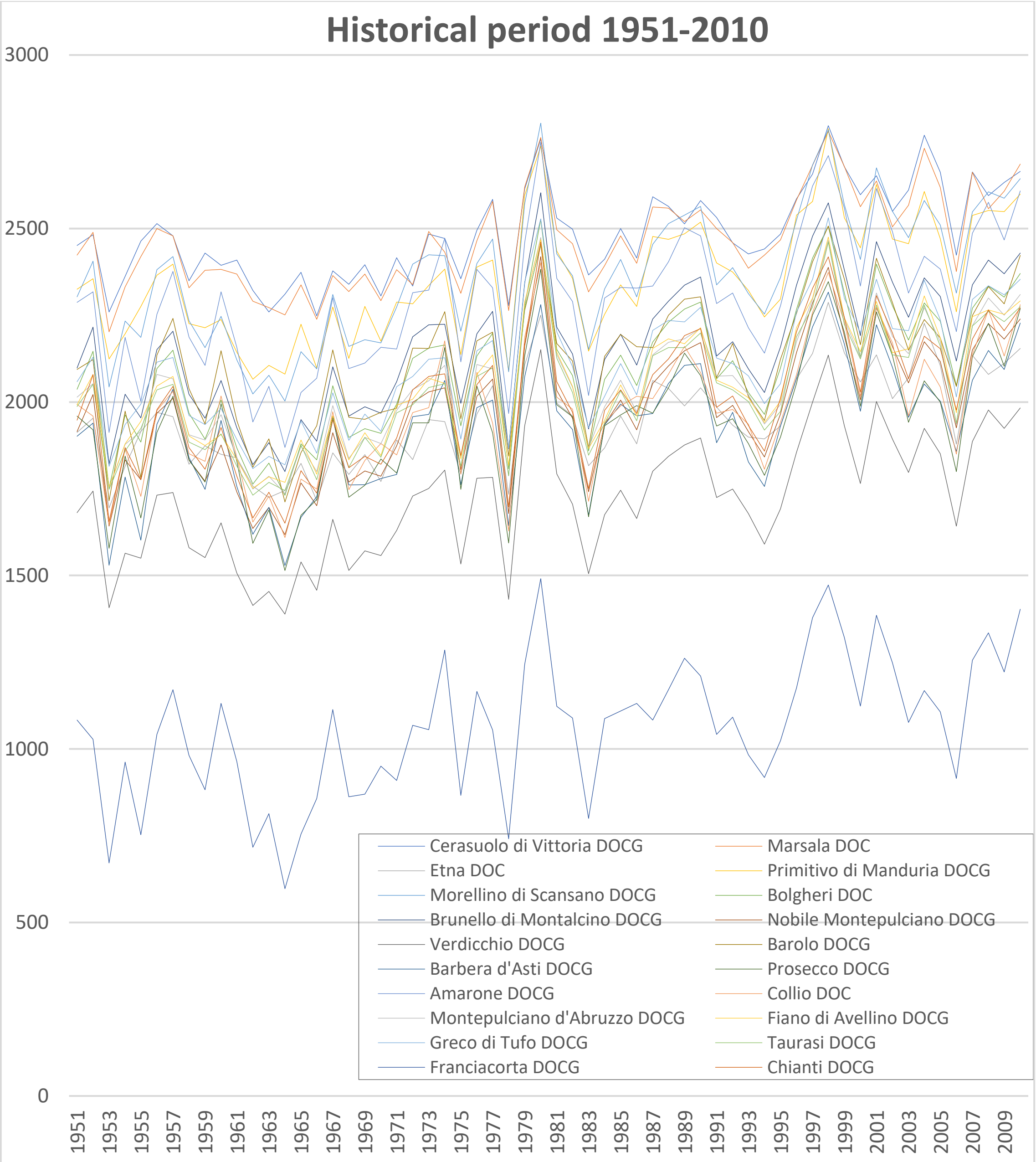

Figure 14: *Time series (1951-2010) with Huglin Index values on the twenty locations calculated with historical values.*

It is important to have insights into the future risks involved. For this reason, a comparison between the two scenarios chosen is made.

In Figure 13, there is a representation of the index values in the projected period with an RCP of 2.6.

While in Figure 14 instead are described the index values in the projected period with an RCP of 6.0.

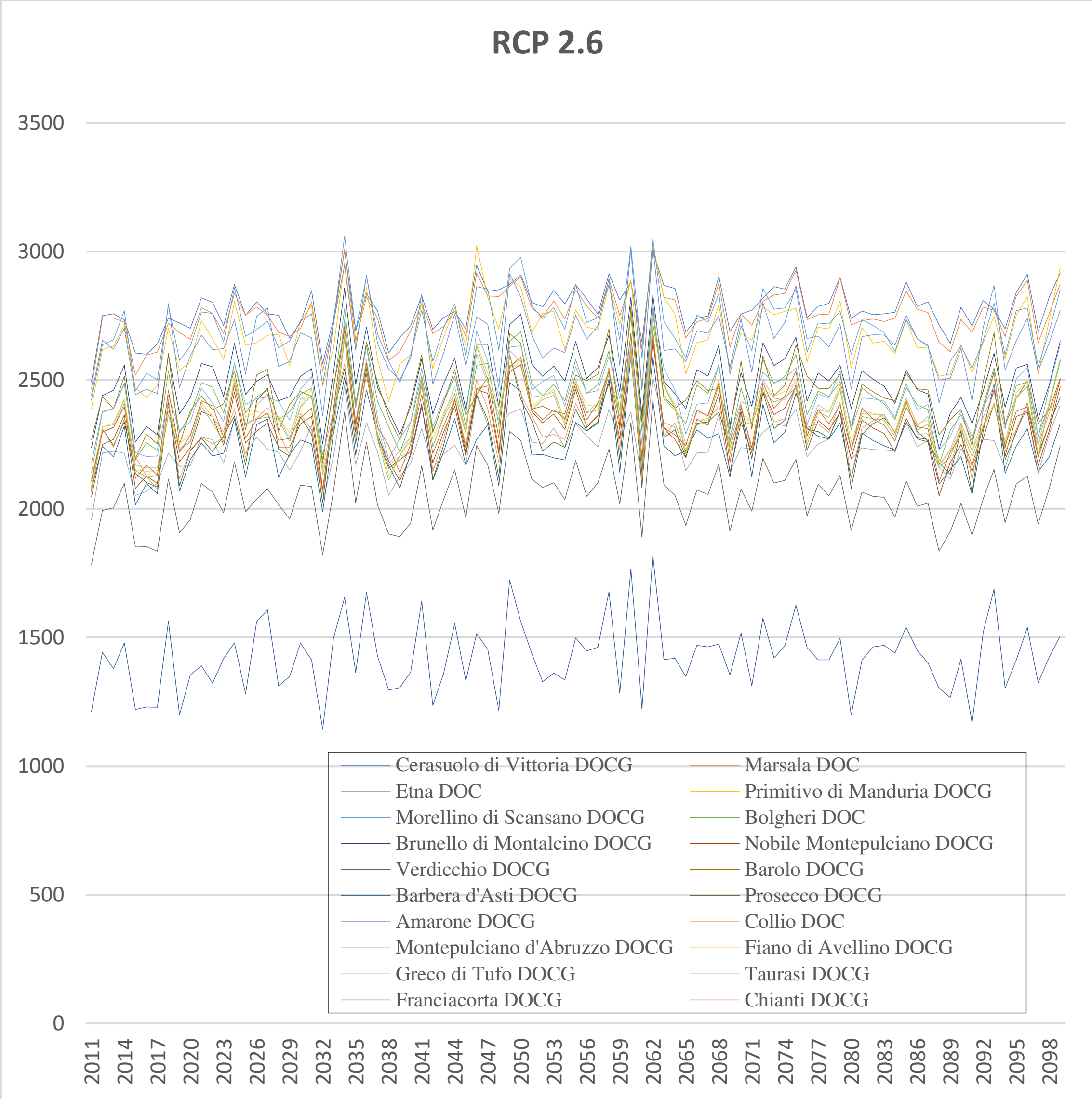

Figure 15: *Time series (2011-2099) with Huglin Index values on the twenty locations. The index is calculated with RCP 2.6 projected temperatures values.*

In RCP 2.6, the indexes fluctuate along with similar values. In general, from this representation, we cannot individuate a clear trend in values that can be found instead on the RCP 6.0 projections of the values. In this scenario of emissions, instead, the movement is clearly upward.

Recalling Table 13, on paragraph 3.3.1, for Huglin Index, some studies identify the lowest and higher values as limits for vineyards culture (Huglin (1978), Tonietto and Carbonneau (2004), Jones et al. (2010)). Namely, a threshold for cultivation is posed over 3000. In the historical period, this threshold was never reached. In The graph representing the RCP 2.6, we can notice that this limit is crossed only for a small portion of the years and for a few locations. However, this is not the same, as we will see, for the RCP 6.0

graph. Indeed, in RCP 2.6, this limit is crossed only a few years in periods in the middle, while for RCP6.0, it becomes a persistent trend for some locations.

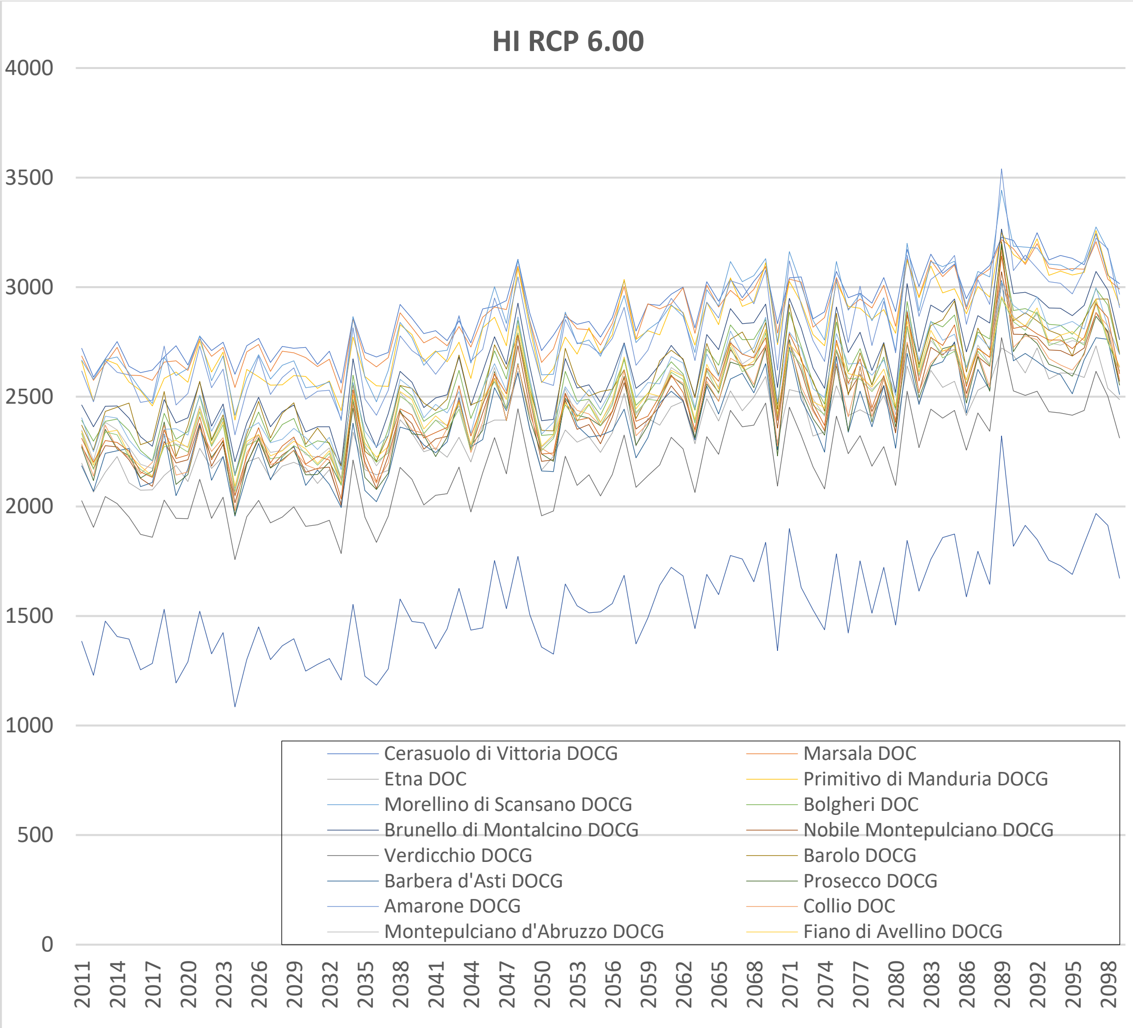

Figure 16: *Time series (2011-2099) with Huglin Index values on the twenty locations. The index is calculated with RCP 6.0 projected temperatures values.*

To have a better comprehension of the data, we use some tables. We furthermore divide data into six different periods, and we calculate the average value for these periods:

- A baseline historical period that goes from 1951 to 1990.

- Other five periods of twenty years each (1991-2010/2011-2030/2031-2050/2051-2070/2071-2090), we disregard the last nine years period to be consistent with the twenty years.

We consider the mean values for each location of the baseline historical period (1951-1990) as a benchmark. Italian wine denominations developed from the end of WWII. Furthermore, Italian wine production passed through the years from an orientation towards quantity production to quality (Pomarici (2021)). Namely, after a period of crisis in 1985 due to the Methanol Scandal, it reached international success from 2000. Due to this historical development, it is fair to assume that the climatic period from 1951 to 1990 could be a proxy for the climatic conditions optimal for the Italian viticulture in the locations chosen and, more precisely, the mean of the Huglin index on each location for this period could be used as a reference value from which measure the change. To sum up, these are our assumptions:

- We consider the climatic period from 1951 to 1990 as a baseline reference. We assume that this period's mean values for each location are optimal for the varieties of grapes in the denominations of these locations.

- The differences between the projected values and this baseline will be used as a risk metric in a proportional sense. Namely, the higher is this shift, and the higher is the risk of the location in the period considered.

As stated before, one of the crucial insights that this analysis aims to underline is the presence of harmful values relating to the limits of 3000 units fixed from studies on the Huglin Index for the suitability conditions of the vineyards.
To underline this aspect proposed in Table 13 of this chapter with the values of the index, we opted for two difference thresholds:

- Values over the 2700-threshold are highlighted in red. These values that represent very warm region identified in Jones et al. (2010) indicate the approach of the non-cultivation limits.

- Values over the 3000-threshold are highlighted in bold red. This threshold represents too hot region identified in Jones et al. (2010), and indicates the reaching of the non-cultivation limit (Huglin (1978)).

This notation of both color and style is also used in tables in the Appendix. Therefore, this notation gives a more detailed representation of the data in the simulated scenarios. Tables 14 and 15 describe the mean values of the Huglin Index in the periods individuated before for each location. The baseline is a forty-year period from 1951 to 1990, while the other periods are twenty-years. The historical values (baseline and 1991-2010) in both figures are highlighted in grey. Regarding the projected values, Table 14 represents the projected RCP 2.6 mean values of the periods considered. From Table 14, we can derive that:

- There are no locations that reach the limit value of 3000.
- Only four locations reach the thresholds of 2700; these are Cerasuolo di Vittoria DOCG, Marsala DOCG, Primitivo di Manduria DOCG, Morellino di Scansano DOCG; these last two, however, exits this threshold in the very last period considered.
- In general, we could see an increasing trend in mean values in all the locations until 2051-2070, followed by a decrease in the last period 2071-2090.

Table 15, instead, represents the mean values of the historical and projected 6.0 Huglin Index. In this case, there is a steeper increasing trend. The main points that could be observed are:

- In three locations: Marsala DOC, Cerasuolo di Vittoria, Morellino di Scansano DOCG the mean value of the index in the period 2031-2050 reaches the threshold of 2700. In these three locations in 2071-2090, the mean value of the period overcome the threshold limit for the cultivation (3000).
- In the period 2051-2070, two other locations reach the threshold of 2700; these are Amarone DOCG and Primitivo di Manduria DOCG. These two locations then get a mean value slightly near 3000 units (2964 and 2961).
- In the period 2071-2090, other five locations reach the thresholds of 2700; these locations are Bolgheri DOC, Brunello di Montalcino DOCG, Barolo DOCG, Greco di Tufo DOCG. In this last period consider only two locations has a mean value lower than 2500, these are Franciacorta DOCG and Verdicchio DOCG

Mean of the period (RCP 2.6)	Baseline	1991-2010	2011-2030	2031-2050	2051-2070	2071-2090
Cerasuolo di Vittoria DOCG	*2432*	*2594*	2720	2780	2809	2794
Marsala DOC	*2410*	*2573*	2694	2756	2783	2765
Etna DOC	*1894*	*2062*	2189	2253	2278	2257
Primitivo di Manduria DOCG	*2292*	*2482*	2613	2711	2720	2667
Morellino di Scansano DOCG	*2300*	*2505*	2656	2732	2753	2685
Bolgheri DOC	*2029*	*2230*	2383	2455	2476	2418
Brunello di Montalcino DOCG	*2092*	*2296*	2450	2523	2543	2483
Nobile Montepulciano DOCG	*1906*	*2109*	2260	2337	2356	2295
Verdicchio DOCG	*1657*	*1850*	1995	2080	2097	2039
Barolo DOCG	*2061*	*2231*	2394	2456	2478	2451
Barbera d'Asti DOCG	*1868*	*2042*	2206	2268	2290	2261
Prosecco DOCG	*1879*	*2061*	2252	2316	2334	2300
Amarone DOCG	*2233*	*2424*	2608	2670	2689	2653
Collio DOC	*1917*	*2091*	2265	2336	2355	2317
Montepulciano d'Abruzzo DOCG	*1986*	*2175*	2313	2403	2421	2360
Fiano di Avellino DOCG	*1983*	*2177*	2312	2399	2412	2359
Greco di Tufo DOCG	*2041*	*2234*	2369	2458	2472	2416
Taurasi DOCG	*1966*	*2158*	2293	2384	2397	2341
Franciacorta DOCG	*1004*	*1182*	1375	1437	1455	1427
Chianti DOCG	*1938*	*2142*	2298	2369	2388	2335

Table 14: *Mean values of the Huglin Index for the twenty areas for each period considered. Baseline refers to the period 1951-1990 used as a benchmark of optimal climate conditions. In the grey left part the index is calculated using historical temperatures while in the right white part the index is calculated with projected temperatures on RCP 2.6. Mean values over 2700 are highlighted in red, while those over the threshold of 3000 are highlighted in bold red.*

Mean of the period (RCP 6.0)	Baseline	1990-2010	2010-2030	2030-2050	2050-2070	2070-2090
Cerasuolo di Vittoria DOCG	*2432*	*2594*	2692	2803	2916	**3036**
Marsala DOC	*2410*	*2573*	2661	2772	2890	**3007**
Etna DOC	*1894*	*2062*	2158	2269	2389	2507
Primitivo di Manduria DOCG	*2292*	*2482*	2588	2694	2840	2961
Morellino di Scansano DOCG	*2300*	*2505*	2614	2724	2866	**3017**
Bolgheri DOC	*2029*	*2230*	2339	2454	2591	2744
Brunello di Montalcino DOCG	*2092*	*2296*	2404	2522	2660	2817
Nobile Montepulciano DOCG	*1906*	*2109*	2217	2332	2472	2625
Verdicchio DOCG	*1657*	*1850*	1961	2068	2216	2348
Barolo DOCG	*2061*	*2231*	2371	2466	2607	2737
Barbera d'Asti DOCG	*1868*	*2042*	2179	2279	2418	2553
Prosecco DOCG	*1879*	*2061*	2214	2314	2467	2594
Amarone DOCG	*2233*	*2424*	2565	2676	2821	2964
Collio DOC	*1917*	*2091*	2231	2333	2482	2607
Montepulciano d'Abruzzo DOCG	*1986*	*2175*	2284	2386	2540	2655
Fiano di Avellino DOCG	*1983*	*2177*	2275	2397	2537	2670
Greco di Tufo DOCG	*2041*	*2234*	2335	2451	2595	2722
Taurasi DOCG	*1966*	*2158*	2260	2376	2521	2648
Franciacorta DOCG	*1004*	*1182*	1343	1438	1590	1713
Chianti DOCG	*1938*	*2142*	2250	2373	2507	2671

***Table 15**: Mean values of the Huglin Index for the twenty areas for each period considered. Baseline refers to the period 1951-1990 used as a benchmark of optimal climate conditions. In the grey left part the index is calculated using historical temperatures while in the right white part the index is calculated with projected temperatures on RCP 6.0. Mean values over 2700 are highlighted in red, while those over the threshold of 3000 are highlighted in bold red.*

The trends highlighted in these two tables suggest that it might be helpful to compare the two scenarios of emission.

Figure 17 describes the differences between the projected values of RCP 6.0 and the projected values of RCP 2.6. The formula used is the following.

[13]

$$DELTA_{6.0\rightarrow 2.6} = HuglinIndex_{6.0} - HuglinIndex_{2.6}$$

This formula is also used to calculate Table 25 in the Appendix.

Namely, Table 25 in the Appendix is plotted in Figure 17. This graph gives us insights into the distributions of the differences between the two emission scenarios.

We could see looking at the chart that until 2055 there exist negative values indicating an upper value for RCP 2.6 compared to the exact locations and same years in RCP 6.0. These negative values suggest a similarity in the two emissions scenarios in the short run. Nevertheless, a massive difference between the two scenarios appears in the long run. This similarity in the short run is a significant result that indicates that even if there will be a decreasing trend on GHG emissions and we will enter the best scenario for impacts, there will not be significant differences in the short run.

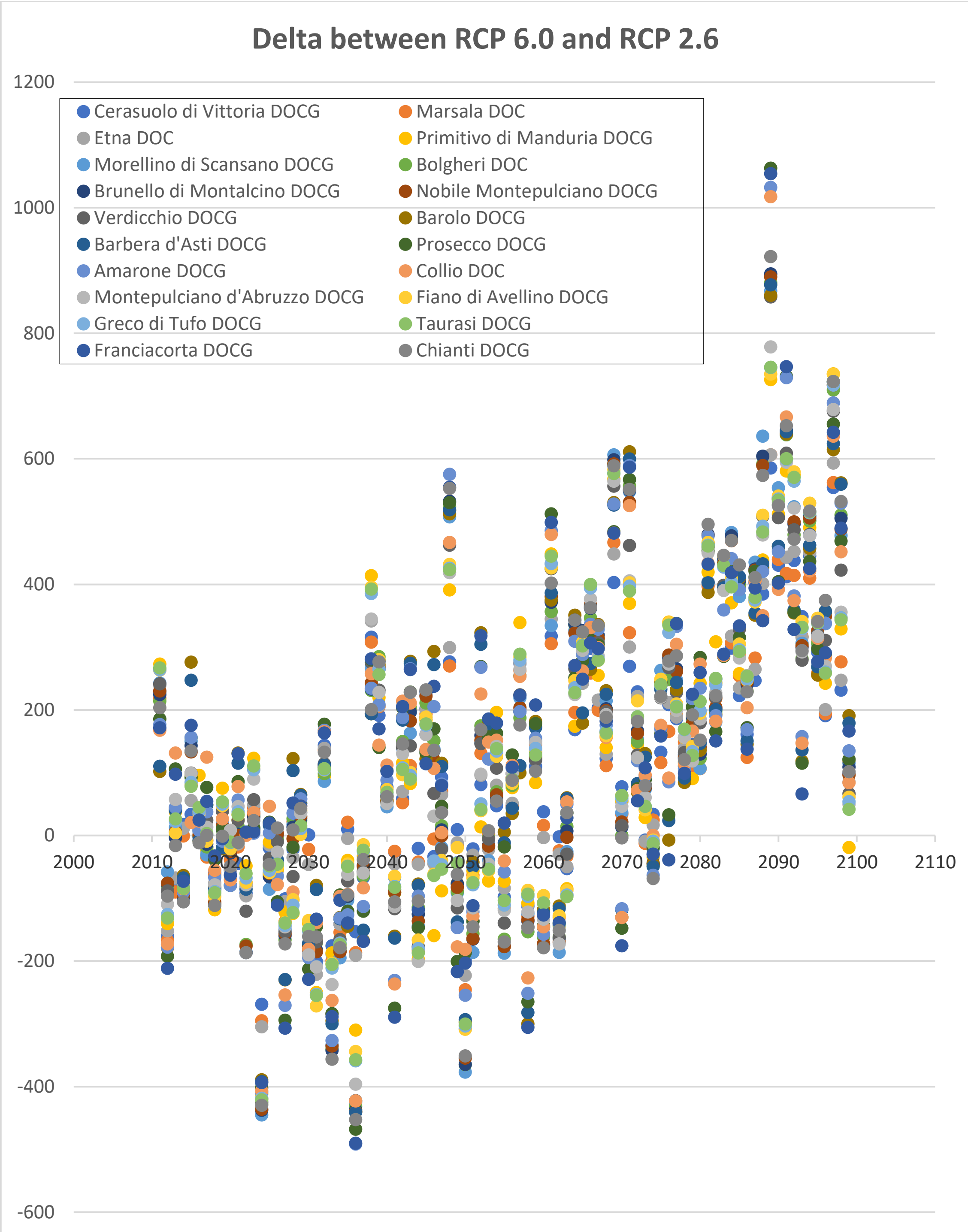

Figure 17: *plotted data values of Table 25 of the Appendix. Delta calculated with equation [13], that is, the differences between the projected Huglin Index values of RCP 6.0 and the projected values of RCP 2.6, covering the projected period (2011-2099).*

Up to now, we analyze data referring only to the mean of the periods. In this way, we could understand how much a region will move closer to the threshold limits (Huglin (1978), Tonietto and Carbonneau (2004), Jones et al. (2010)) individuates before in Table 13. This gives us information about the long run and, more precisely, provides us with a

threshold of years where the impacts of climate change would be overcome only with drastic further adaptation, which maybe will not be sufficient (also with varieties modifications).
Another risk metric that we can use is the difference between projected values and a baseline. As seen before, we fixed as baseline period 1951-1990. We further assume the optimal climate conditions for the Italian wine regions considered are given by this period and that, furthermore, the optimal Huglin Index for each location are the mean values of this baseline period.
From this starting point, we use these equations to transform our data:

[14]

$$Baseline_l = Mean_{1951\rightarrow1990}\left(HuglinIndex_l\right)$$

Where l is one of the locations considered in our analysis, so for every location is calculated its specific baseline.

From the baseline, we could calculate two types of data: one derives from the difference between a future period mean and the baseline, and another derives from the difference between the projected yearly value of the Huglin Index and the baseline.

[15]

$$MeanDifferences_{l,r,j\rightarrow k} = Mean_{j\rightarrow k}\left(HugliIndex_{l,r}\right) - Baseline_l$$

[16]

$$MeanDifferences_{l,r,y} = HugliIndex_{l,r} - Baseline_l$$

Where l is the location considered, r is the RCP (2.6 or 6.0), j→k is the period considered for the mean period, and y is the year considered for the difference.

While the transformation [15] underlines a trend, the transformation [16] profoundly captures the yearly fluctuations of the index from the baseline value. The yearly fluctuations underline the stochastic nature of the process.

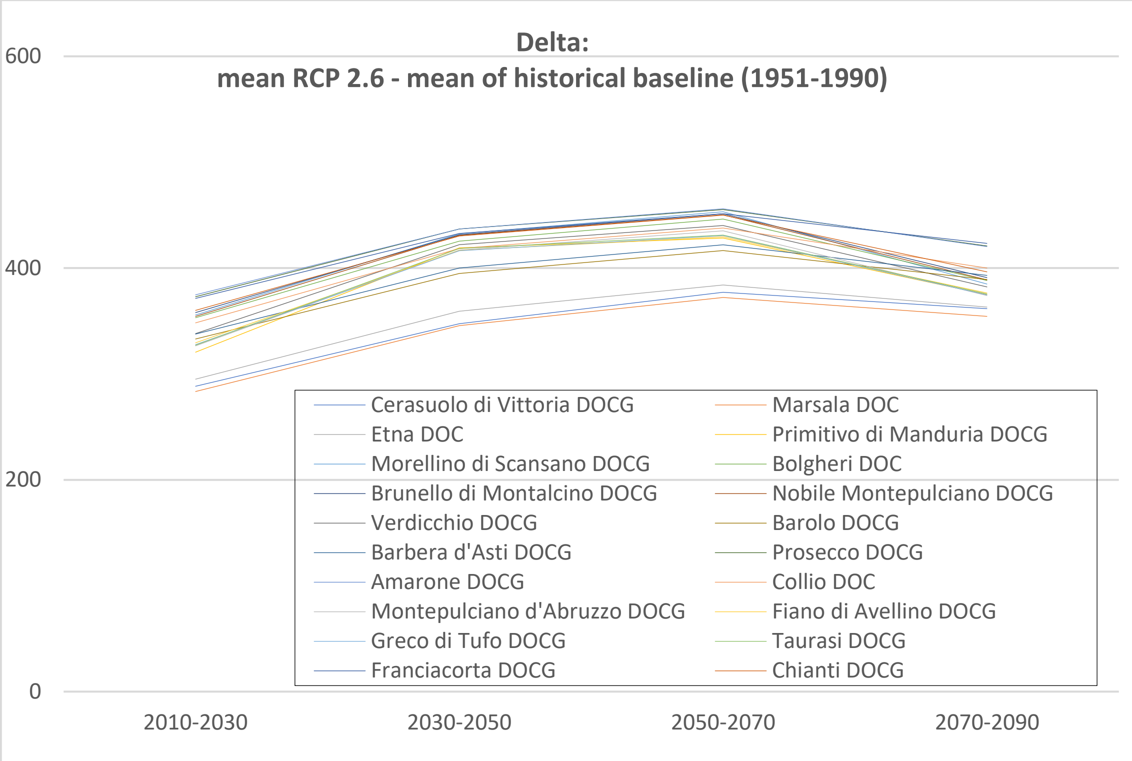

Figure 18: *plot of the equation [15], the delta between the period's mean with RCP 2.6 and the Baseline. Baseline described in equation [14]as the mean value of HI on the period 1951-1990.*

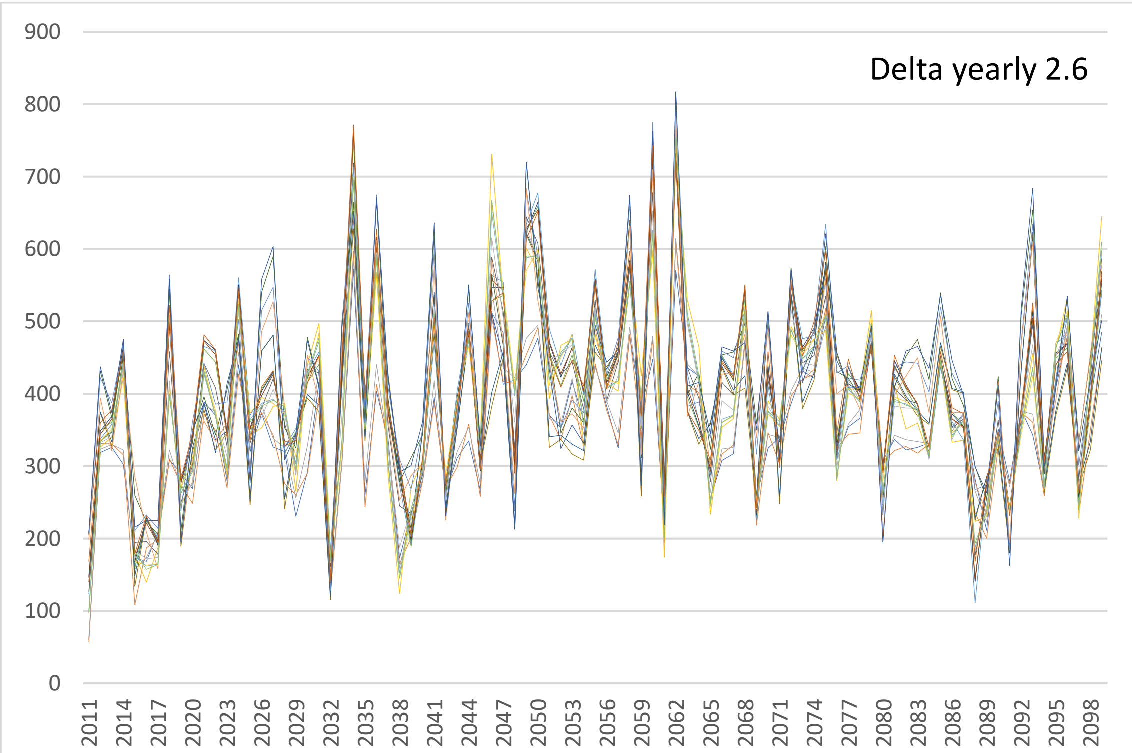

Figure 19: *plot of the equation [16], that is the delta between the yearly HI projected RCP 2.6 value and the Baseline described in equation [14]as the mean value of HI on the period 1951-1990.*

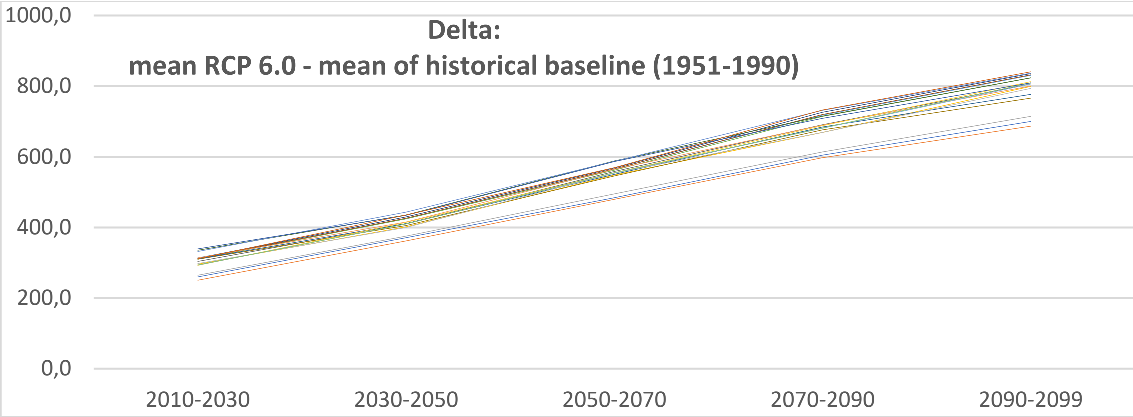

Figure 20: *plot of the equation [15], the delta between the period's mean with RCP 6.0 and the Baseline. Baseline described in equation [14]as the mean value of HI on the period 1951-1990.*

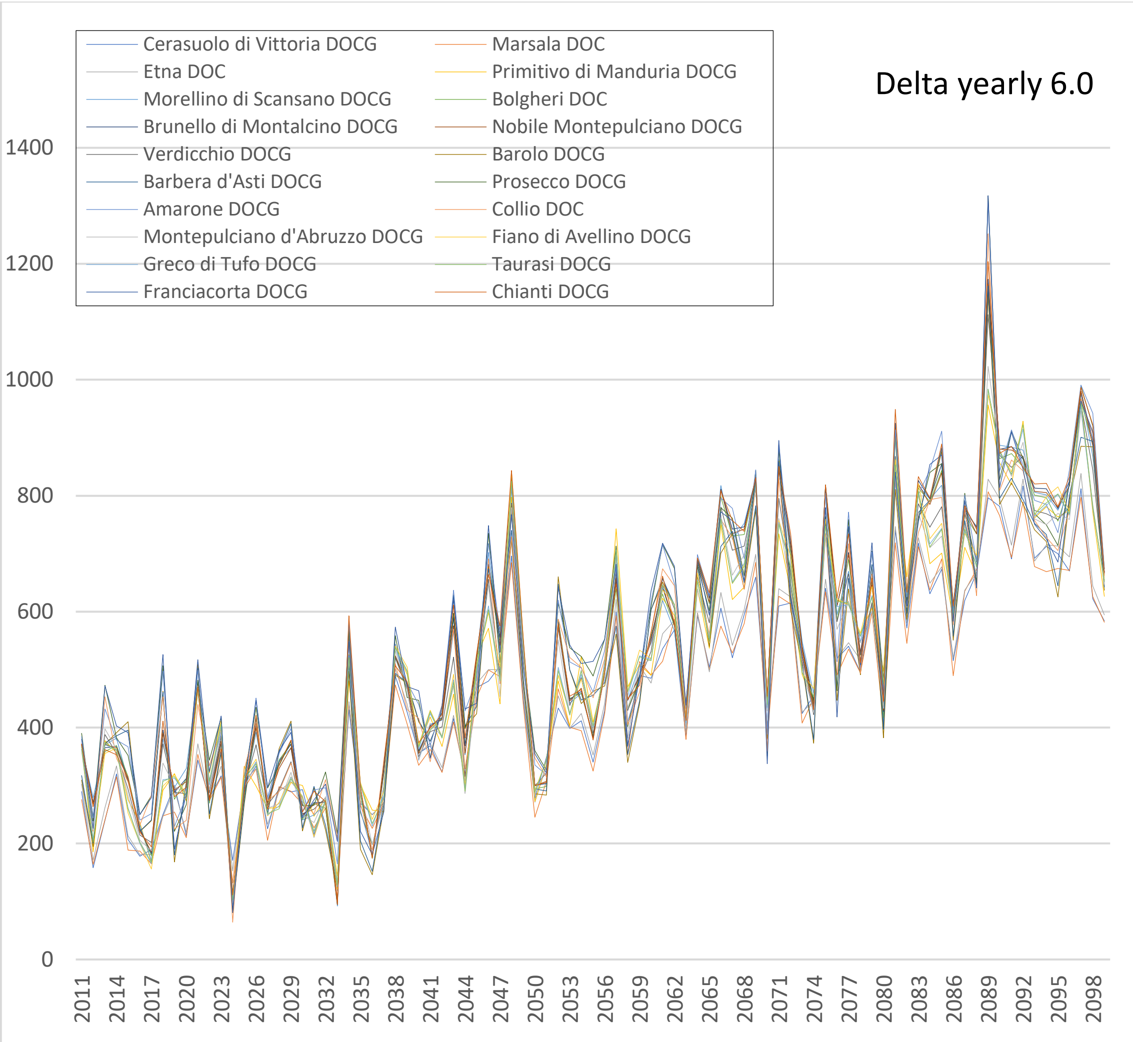

Figure 21: *plot of the equation [16], that is the delta between the yearly HI projected RCP 6.0 value and the Baseline described in equation [14]as the mean value of HI on the period 1951-1990.*

From the graphs in Figures 18-19 and 20-21 described in the previous two pages we could highlight some points:

- In RCP 2.6 trajectories in the mean of the period of transformed data, described in Equation 15 and reported in Figure 18, there is an increasing trend in the first part of the projected period. This trend lasts until the 2051-2070 period, when a decreasing trend starts.

- In RCP 6.0 trajectories, the same trend described in the previous point is instead continuously increasing. This aspect can be noted in Figure 20.

If we look to the second graph, the one that described the data transformation in Equation [16], we can consider the peak in values. These peaks are extreme years fluctuations in terms of the Huglin Index for the locations considered. While for RCP 2.6 only in one year the peak overcomes the value of 800 (Figure 19), for what regards RCP 6.0 the peak reaches values much higher if compared to RCP 2.6; more precisely, these values are over 1300 (Figure 21).
We recall data in two tables to summarize the two dimensions that could give us insights into future economic shocks. Namely, in Table 16 are described RCP 2.6 data while in Table 17. These two dimensions are:

- The reach of the "***3000-threshold***". This value is considered as a fixed limit for the cultivation (Huglin (1978), Tonietto and Carbonneau (2004), Jones et al. (2010)). It can be stated as the default limit for the wine firms on the locations that overcome this limit.

- The shift from the "***Baseline Index.***[29]" This shift would cause a proportional shock in revenues (higher shift, greater shock) due to the costs for adaptations and the decrease in wine price due to the loss of the terroir competitive advantage and historical identity caused by the necessary modifications in production techniques

[29] Equation [14] gives a definition

or cultivated varieties. However, the magnitude of the shock is non-linear and impossible to assess. This risk metric is only proportional to the shock.

RCP 2.6	2011-2030		2031-2050		2051-2070		2071-2090	
	Delta	Mean	Delta	Mean	Delta	Mean	Delta	Mean
Franciacorta DOCG	371	1375	433	1437	451	1455	423	1427
Verdicchio DOCG	338	1995	422	2080	440	2097	382	2039
Etna DOC	295	2189	359	2253	384	2278	363	2257
Barbera d'Asti DOCG	338	2206	400	2268	422	2290	393	2261
Prosecco DOCG	373	2252	437	2316	455	2334	421	2300
Nobile Montepulciano DOCG	354	2260	431	2337	450	2356	389	2295
Collio DOC	348	2265	418	2336	438	2355	400	2317
Taurasi DOCG	327	2293	418	2384	431	2397	375	2341
Chianti DOCG	360	2298	430	2369	450	2388	397	2335
Fiano di Avellino DOCG	329	2312	417	2399	430	2412	376	2359
Montepulciano d'Abruzzo DOCG	327	2313	417	2403	435	2421	374	2360
Greco di Tufo DOCG	328	2369	416	2458	431	2472	375	2416
Bolgheri DOC	353	2383	425	2455	446	2476	388	2418
Barolo DOCG	333	2394	395	2456	417	2478	389	2451
Brunello di Montalcino DOCG	358	2450	431	2523	451	2543	391	2483
Amarone DOCG	375	2608	437	2670	456	2689	420	2653
Primitivo di Manduria DOCG	321	2613	419	2711	428	2720	375	2667
Morellino di Scansano DOCG	356	2656	432	2732	453	2753	385	2685
Marsala DOC	283	2694	346	2756	372	2783	354	2765
Cerasuolo di Vittoria DOCG	288	2720	348	2780	377	2809	362	2794

Table 16: *recap of the two risk metrics used. In each period, in the first column, there is the delta between the RCP 2.6 mean value of the period and baseline period (1951-1990) with conditional formatting that highlights the higher values for each period on a scale of reds. A more detailed and non-averaged representation of this risk metric can be found in Figure 19. While on the second column of each period there is the mean value of the index in the period with the values over the 2700-threshold are highlighted in red and the values over the 3000-threshold are highlighted in bold red. A more detailed and non-averaged representation of this risk metric can be found in Figure 15.*

RCP 6.0	2011-2030		2031-2050		2051-2070		2071-2090	
	Delta	Mean	Delta	Mean	Delta	Mean	Delta	Mean
Franciacorta DOCG	339	1343	434	1438	586	1590	709	1713
Verdicchio DOCG	304	1961	411	2068	558	2216	691	2348
Etna DOC	264	2158	375	2269	495	2389	613	2507
Barbera d'Asti DOCG	311	2179	410	2279	550	2418	685	2553
Prosecco DOCG	335	2214	435	2314	588	2467	715	2594
Nobile Montepulciano DOCG	311	2217	426	2332	566	2472	720	2625
Collio DOC	314	2231	416	2333	564	2482	690	2607
Chianti DOCG	311	2250	435	2373	569	2507	732	2671
Taurasi DOCG	294	2260	410	2376	555	2521	682	2648
Fiano di Avellino DOCG	292	2275	414	2397	554	2537	688	2670
Montepulciano d'Abruzzo DOCG	298	2284	400	2386	553	2540	669	2655
Greco di Tufo DOCG	293	2335	409	2451	553	2595	681	2722
Bolgheri DOC	310	2339	424	2454	562	2591	714	2744
Barolo DOCG	310	2371	405	2466	546	2607	676	2737
Brunello di Montalcino DOCG	313	2404	430	2522	568	2660	726	2817
Amarone DOCG	332	2565	443	2676	587	2821	731	2964
Primitivo di Manduria DOCG	296	2588	402	2694	548	2840	669	2961
Morellino di Scansano DOCG	314	2614	424	2724	566	2866	717	**3017**
Marsala DOC	250	2661	362	2772	480	2890	597	**3007**
Cerasuolo di Vittoria DOCG	260	2692	371	2803	484	2916	604	**3036**

Table 17: *recap of the two risk metrics used in the analysis. In each period, in the first column, there is the delta between the RCP 2.6 mean value of the period and baseline period (1951-1990) with conditional formatting that highlights the higher values for each period on a scale of reds. A more detailed representation of this risk metric can be found in Figure 21. While on the second column of each period there is the mean value of the index in the period with the values over the 2700-threshold are highlighted in red and the values over the 3000-threshold are highlighted in bold red. A more detailed representation of this risk metric can be found in Figure 16.*

From Tables 16 and 17, we can extract insights from the two risk metrics dimensions.

First dimension: ***"3000-threshold[30]"***

- RCP 2.6: four areas overcome the threshold of 2700 in the two periods in the middle (2031-2050 and 2051-2070). However, in the period 2071-2090, three out of four of these locations newly are under this threshold. Only Cerasuolo di Vittoria DOCG stays over this threshold in all the four mean values considered periods.

- RCP 6.0: there is an increasing trend of areas that overcome the threshold of 2700. Namely, three areas in 2031-2050 (Morellino di Scansano DOCG, Marsala DOC, Cerasuolo di Vittoria DOCG), other two in 2051-20170 (Primitivo di Manduria DOCG, Amarone DOCG), and other four in 2071-2090 (Brunello di Montalcino DOCG, Barolo DOCG, Bolgheri DOC,Greco di Tufo DOCG). In this last period, nine areas over twenty, almost 50% of the areas considered in this analysis reached the 2700 threshold. In the last period, the three areas that firstly reach the 2700 values overcome the 3000 thresholds (Morellino di Scansano DOCG, Marsala DOC, Cerasuolo di Vittoria DOCG).

- Comparison RCP 2.6 and 6.0: RCP 2.6 shows in some cases higher mean values in the first half of the periods and lower values in the second half. This trend was already observed in Figure 18. There are substantial insights from the two scenarios. In RCP 2.6, the 3000-threshold is never reached in mean, while in RCP 6.0 is reached or almost reached in nine over twenty locations.

Second dimension: ***"shift from the Baseline Index[31]"***

- RCP 2.6: in all the locations, there is an increasing trend until the period 2051-2070, when it starts a decreasing trend in values of this risk metric.

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[30] Proxy of the default limit.
[31] Following data transformation of Equation [15]

- RCP 6.0: in all the locations there are an increasing trend over the future periods.

- Comparison RCP 2.6 and 6.0: surprisingly, there are lower mean values on this risk metric in the Sicilian locations. The reason is not apparent, so it is necessary a further investigation. Reversely, some locations have values constantly over the mean of the other locations, such locations are, e.g., Franciacorta DOCG and Amarone DOCG, also in this case is not clear the motivations behind this trend. However, it emerges that exist differences in the trends analyzed in the various area of Italy.

To conclude the analysis, we must also state that the dataset containing the raw data used to calculate the Index in the analysis may have some issues. This observation is underlined in Hsiang (2016), where it is stated that climate data sets that derive from gridded data which usually are the spatial interpolation of meteorological station data (if historical data) or they are augmented with a physics-based model (if projected data) may create some issues. Moreover, it appears not clear if the procedures that give these data results could influence the resulting estimated variables' statistical description. For these reasons, we do not apply an econometric analysis based on the findings of this last paragraph, but we limit to compare historical values with the projected ones, making assumptions based on the main studies that link climate change with wine sectors revised on this thesis.
Moreover, our analysis is based on the 3000-threshold-limit of viticulture cultivation ((Huglin (1978), Tonietto and Carbonneau (2004), Jones et al. (2010)) and other assumptions that we added (such as the "baseline period" described in Equation [14] and based on historical wine sector development in Italy mentioned in Pomarici (2021)). Finally, our analysis gives insights only on the future economic damages derived from viticultural zoning relocation. However, the Huglin Index does not capture all the complex economic consequences of climate change on viticulture. Therefore, the analysis made in this chapter could not capture extreme hazards that are described in Table 9 and Table 10 in paragraph 2.3. Therefore, we could give only a qualitative description of the possible consequences for these climate physical risk' dimensions.

CONCLUSIONS

In this thesis, we analyze the effects of climate change on the wine sector. We concentrate our analysis on the Italian wine sector. In particular, we refer to wine firms with bottled wine production (we do not consider bulk wine production) and owned vineyards. These choices have been made to capture a vast set of challenges that arise when a multidimensional relation, such as wine production and climate, is studied.

In this thesis, the primary purpose has been to identify the richness of this sector. The features identified in Table 6 in paragraph 2.1.1 have been touched by analyzing the relations between wine and climate changes. In particular, the literature review of the impacts (paragraph 2.1.3-2.1.4-2.1.5) has found that these relations are multidimensional and mainly nonlinear. This peculiarity of the wine production, jointed with the dynamics behind the climate change (such as tipping point, non-stationarity, changes in the shape of the statistical distribution of climate variables), makes not easy an economic assessment of the climate risks related to climate change. Moreover, methodological issues arise when a standard econometric analysis is made to investigate such relations. Some of these issues could not be solved. One of these issues is the backward-looking perspective of a standard econometrics analysis. This perspective may provoke misleading results if the events we want to estimate are unprecedented or the shape of the statistical distribution of the regression variables used is continuously changing (as seen in Figure 2).

For these reasons, in paragraph 2.3, we apply a credit risk qualitative analysis on the main climate-related hazards that impact the wine sector. This analysis state that climate change could modify both the probability of default and the recovery rate of wine firms. These modifications consequently increase the credit risk related to wine firms' loans. This credit risk increase may provoke a credit rationing towards the sector.

Finally, in Chapter 3, an analysis based on a viticultural indicator (Huglin Index) is performed on twenty selected Italian areas. This analysis is forward-looking as it compares future projections with historical values both calculated using the Copernicus dataset. Namely, two projected emissions scenarios (RCP 2.6 and RCP 6.0) are used. These are associated with a best-case scenario (RCP 2.6) and a worst-case scenario (RCP 6.0). In addition, the analysis identifies risk metrics. Such metrics analyze only the risk of viticultural zoning modifications.

Moreover, a risk indicator gives a benchmark for a default scenario of the wine firms. This indicator is based on the viticultural cultivation limit identified for the Huglin Index (mentioned in (Huglin (1978), Tonietto and Carbonneau (2004), Jones et al. (2010)). This metric states that on RCP 6.0, on nine over twenty locations this limit is reached (3) or almost reached (6) in the last twenty-year period considered (2071-2090). While in RCP 2.6 values, the indicator shows an increasing trend in the first half of the projected period (until 2051-2070) and a decreasing trend after this period. However, it almost reached the threshold value in three locations.

To conclude, we must observe that this approach has some issues. One is given by the non-sufficient spatial resolution of the dataset used. In particular, averaging data over large areas may smooth nonlinear dimensions present in specific sites. Another issue sources can be detected on the dataset used. Namely, this dataset considers only one possible run of the predicted scenarios; therefore, it retains only partial information.

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APPENDIX

[1] Antinori wineries diversification

Wineries:	**Regions:**	**Grape varieties:**
Tenuta Tignanello	Toscana	Sangiovese, Cabernet Sauvignon, Cabernet Franc, Malvasia, Trebbiano
Badia a Passignano	Toscana	Sangiovese
Pèppoli	Toscana	Sangiovese
Antinori	Toscana	sangiovese canaiolo ciliegiolo colorino malvasia nera mammolo cabernet sauvignon cabernet franc
Pian delle vigne	Toscana	sangiovese (brunello)
Tenuta Guado al Tasso	Toscana	Cabernet sauvignon, merlot, syrah, cabernet franc, petit verdot, vermentino
Tenuta Montenisa	Lombardia	chardonnay, pinot nero, pinot bianco
Prunotto	Piemonte	Nebbiolo, barbera, dolcetto, moscato bianco, syrah, erbaluce, sauvignon, arneis
Castello della Sala	Umbria	procanico, grechetto, chardonnay, sauvignon blanc, sémillon, pinot bianco, viognier, traminer, Riesling
Jermann	Friuli Venezia Giulia	Ribolla gialla, chardonnay, Pinot bianco, sauvignon, pignolo, pinot grigio, picolit, malvasia, friulano, franconia, pinot nero, Riesling

Table 18: *this table describes the main wineries of Antinori, one of the biggest Italian wine firms with owned vineyards. It is individuated the name of the winery, the region, and the main varieties cultivated.*

[2] Zonin1821 wineries diversification

Wineries:	**Regions:**	**Grape varieties:**
Ca' Bolani	FriuliVenezia Giulia	Cabernet Franc, Friulano, Traminer, Chardonnay, Sauvignon, Pinot Grigio, Pinot Bianco, Merlot, Glera, Muller Thurgau, Refosco.
Castello di Albola	Toscana	Sangiovese, Cabernet Sauvignon, Chardonnay, Trebbiano Toscano, Malvasia del Chianti.
Abbazia Monte Oliveto	Toscana	Vernaccia di San Gimignano
Castello del Poggio	Piemonte	Barbera, Dolcetto, Grignolino, Moscato, Brachetto
Tenuta il bosco oltrenero	Lombardia	Pinot nero, Barbera, Bonarda, Malvasia
Principi di Butera	Sicilia	Nero d'Avola, Cabernet Sauvignon, Merlot, Petit Verdot, Insolia, Syrah, Grillo, Chardonnay
Rocca di Montemassi	Toscana	Syrah, Petit Verdot, Cabernet Sauvignon, Sangiovese, Vermentino
Masseria Altemura	Puglia	Aglianico, Primitivo, Negroamaro, Fiano, Falanghina,
Zonin1821	Veneto	Cabernet Sauvignon, Cabernet Franc, Merlot, Trebbiano di Lugana, Garganega, Corvina, Rondinella, Molinara, Chardonnay, Pinot Bianco, Pinot Grigio, Glera, Pinot Nero, Ribolla Gialla, Muller Thurgau

Table 19: *this table describes the main wineries of Zonin1821, one of the biggest Italian wine firms with owned vineyards. It is individuated the name of the winery, the region and the main varieties cultivated.*

.

[3] Table with the location on the center of the selected areas

Municipality on the center	Province	Region	N	E
Scicli	Ragusa	Sicilia	36,75	14,75
Salami	Trapani	Sicilia	37,75	12,75
Bronte	Catania	Sicilia	37,75	14,75
Martina Franca	Taranto	Puglia	40,75	17,25
Scansano	Grosseto	Toscana	42,75	11,25
Pomarance	Pisa	Toscana	43,25	10,75
Sovicille	Siena	Toscana	43,25	11,25
Lucignano	Arezzo	Toscana	43,25	11,75
San Severino	Macerata	Marche	43,25	13,25
Sommariva	Cuneo	Piemonte	44,75	7,75
Calosso	Asti	Piemonte	44,75	8,25
Villorba	Treviso	Veneto	45,75	12,25
Marmirolo	Mantova	Lombardia	45,25	10,75
Sgonico	Trieste	Friuli V. G.	45,75	13,75
Filetto	Chieti	Abruzzo	42,25	14,25
San Severino	Salerno	Campania	40,75	14,75
Fragneto Monforte	Benevento	Campania	41,25	14,75
Montaguto	Avellino	Campania	41,25	15,25
Marmetino	Brescia	Lombardia	45,75	10,25
Valdarno	Firenze	Toscana	43,75	11,25

Table 20*: description of the locations on the center of the 0.5°×0.5° areas selected in the analysis, with municipalities, province, region, longitude, latitude*

[4] Maps with vineyards of Bolgheri and Sassicaia DOC

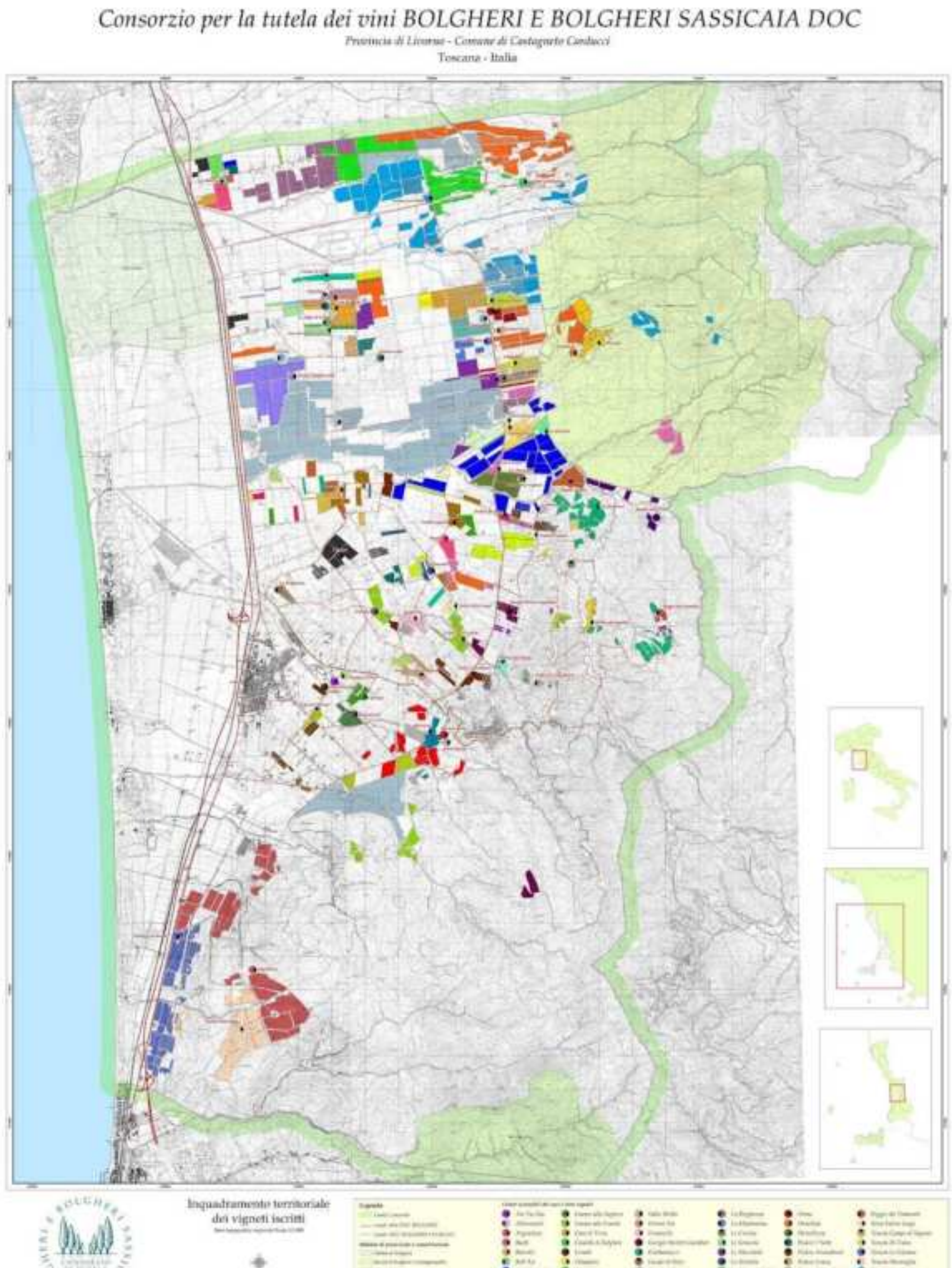

Figure 22: *maps of the vineyards of the denomination of Bolgheri and Sassicaia DOC, that extends for almost 13 × 7.5 Km with 65 producers and 1360 hectares extension.*

[5] Matrix with historical Huglin Index values

HIST	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1951	2451	2424	1913	2325	2304	2036	2098	1915	1681	2093	1901	1959	2287	1993	2014	1992	2059	1987	1083	1948
1952	2482	2489	1953	2356	2406	2146	2216	2022	1743	2122	1939	1920	2318	1959	2053	2079	2130	2051	1028	2079
1953	2260	2202	1695	2124	2043	1751	1822	1642	1407	1715	1530	1578	1912	1646	1753	1755	1815	1749	672	1656
1954	2362	2332	1815	2196	2234	1963	2023	1833	1564	1973	1783	1844	2186	1864	1877	1880	1935	1859	962	1869
1955	2463	2419	1914	2275	2186	1885	1954	1776	1550	1783	1602	1666	2002	1728	1916	1944	1994	1924	753	1776
1956	2514	2500	1971	2365	2382	2096	2151	1967	1731	2135	1935	1912	2253	1975	2079	2046	2114	2035	1042	1978
1957	2479	2479	1957	2398	2419	2149	2204	2011	1739	2241	2037	2017	2376	2031	2067	2073	2128	2051	1171	2045
1958	2349	2329	1820	2226	2234	1967	2023	1833	1580	2038	1840	1832	2187	1850	1906	1903	1961	1885	982	1868
1959	2430	2379	1873	2214	2157	1893	1954	1772	1552	1937	1748	1770	2106	1829	1890	1875	1935	1863	882	1806
1960	2394	2382	1849	2238	2247	2005	2061	1876	1651	2147	1947	1995	2317	2018	1964	1906	1981	1908	1131	1927
1961	2409	2369	1839	2143	2121	1868	1926	1741	1507	1947	1757	1830	2157	1840	1839	1834	1892	1816	964	1786
1962	2321	2291	1758	2066	2023	1764	1820	1635	1414	1813	1619	1593	1942	1655	1749	1751	1808	1731	717	1666
1963	2259	2272	1725	2105	2077	1824	1882	1697	1454	1893	1696	1689	2045	1729	1786	1785	1843	1769	814	1740
1964	2311	2251	1745	2081	2003	1731	1800	1618	1389	1712	1529	1514	1869	1609	1736	1768	1819	1745	597	1651
1965	2374	2338	1823	2224	2145	1879	1949	1767	1539	1855	1668	1673	2027	1778	1873	1891	1945	1876	754	1802
1966	2248	2238	1716	2098	2096	1833	1887	1702	1458	1932	1728	1719	2069	1749	1800	1792	1852	1776	857	1737
1967	2378	2364	1853	2273	2310	2047	2101	1911	1662	2150	1952	1959	2300	1972	1990	1960	2027	1950	1113	1948
1968	2339	2319	1792	2125	2160	1898	1959	1769	1515	1956	1761	1725	2097	1747	1838	1833	1890	1811	863	1810
1969	2396	2369	1848	2276	2179	1923	1986	1801	1571	1950	1761	1760	2113	1831	1898	1912	1965	1898	870	1843
1970	2305	2292	1771	2175	2170	1910	1968	1786	1557	1970	1779	1836	2158	1881	1880	1846	1915	1841	950	1821
1971	2416	2381	1890	2288	2274	1994	2058	1873	1630	1982	1791	1795	2153	1848	1976	1991	2044	1968	910	1896
1972	2334	2339	1834	2283	2397	2126	2188	1999	1729	2155	1958	1940	2315	1970	2036	2008	2073	1992	1068	2035
1973	2483	2491	1950	2336	2424	2155	2222	2029	1751	2154	1965	1940	2323	1983	2061	2069	2123	2042	1056	2073
1974	2472	2432	1943	2383	2422	2164	2224	2041	1804	2260	2062	2157	2472	2176	2106	2054	2127	2053	1285	2081
1975	2355	2313	1792	2136	2204	1932	1997	1806	1533	1952	1762	1748	2116	1792	1842	1837	1893	1815	866	1846
1976	2495	2465	1965	2389	2399	2132	2197	2016	1781	2176	1983	2046	2382	2086	2108	2079	2148	2074	1166	2050
1977	2584	2578	2047	2409	2469	2198	2261	2066	1783	2201	2006	1912	2329	1939	2096	2135	2177	2099	1055	2105
1978	2278	2264	1734	2089	2087	1808	1865	1679	1431	1844	1644	1593	1967	1628	1787	1817	1867	1788	742	1698
1979	2614	2620	2107	2596	2571	2277	2343	2161	1931	2264	2073	2133	2459	2186	2283	2289	2346	2271	1244	2167
1980	2758	2762	2250	2736	2803	2526	2603	2419	2151	2457	2281	2382	2748	2401	2474	2468	2527	2451	1491	2461
1981	2530	2496	1996	2435	2427	2152	2216	2033	1793	2169	1975	1992	2356	2014	2137	2143	2202	2127	1123	2059
1982	2498	2456	1960	2356	2364	2076	2139	1953	1705	2118	1920	1958	2289	1979	2043	2045	2102	2028	1089	1970
1983	2366	2317	1817	2147	2152	1859	1923	1742	1506	1868	1674	1669	2019	1714	1867	1866	1925	1847	800	1751
1984	2412	2393	1867	2253	2326	2066	2122	1935	1675	2132	1934	1932	2300	1942	1987	1947	2016	1938	1088	1976
1985	2500	2479	1960	2337	2411	2135	2195	2005	1745	2195	1994	1962	2330	1989	2063	2050	2111	2032	1110	2035
1986	2415	2400	1879	2275	2303	2048	2106	1919	1664	2159	1960	1989	2328	2016	1971	1960	2021	1945	1131	1967
1987	2592	2562	2062	2477	2455	2173	2239	2053	1800	2157	1967	1968	2334	2010	2136	2154	2206	2133	1084	2079
1988	2564	2558	2039	2468	2514	2230	2291	2104	1844	2250	2054	2041	2404	2080	2172	2182	2235	2157	1171	2124
1989	2513	2520	1989	2484	2538	2268	2337	2148	1876	2297	2106	2141	2502	2160	2182	2168	2230	2157	1262	2191
1990	2580	2553	2040	2518	2564	2288	2360	2171	1896	2303	2111	2076	2478	2084	2213	2214	2272	2199	1211	2212
1991	2532	2500	1985	2400	2337	2067	2133	1955	1725	2070	1883	1931	2284	1968	2075	2063	2126	2055	1042	1985
1992	2459	2459	1933	2374	2387	2119	2174	1991	1749	2169	1970	1952	2314	1978	2076	2042	2111	2035	1091	2017

1993	2427	2385	1899	2322	2313	2027	2095	1915	1679	2016	1828	1880	2214	1935	2022	2013	2075	2002	983	1933
1994	2441	2423	1894	2245	2253	1965	2027	1842	1591	1947	1757	1788	2141	1806	1936	1940	1996	1919	918	1858
1995	2483	2467	1931	2297	2359	2098	2159	1965	1692	2123	1931	1899	2277	1941	1993	2002	2052	1973	1023	2012
1996	2585	2582	2066	2539	2524	2267	2336	2143	1855	2255	2069	2053	2459	2078	2174	2215	2260	2188	1176	2202
1997	2657	2682	2140	2578	2683	2415	2478	2285	2000	2404	2216	2251	2622	2259	2296	2300	2354	2273	1378	2327
1998	2796	2780	2287	2787	2784	2507	2574	2388	2135	2507	2316	2347	2710	2374	2465	2475	2531	2461	1473	2418
1999	2678	2679	2142	2531	2569	2314	2381	2190	1932	2354	2167	2201	2559	2230	2239	2243	2299	2223	1321	2244
2000	2598	2563	2058	2444	2411	2129	2191	2006	1765	2165	1973	1988	2334	2017	2128	2145	2200	2124	1124	2028
2001	2652	2637	2136	2627	2674	2398	2462	2272	2001	2414	2223	2259	2615	2273	2314	2289	2353	2280	1385	2306
2002	2549	2505	2009	2470	2550	2277	2345	2159	1893	2286	2100	2133	2490	2170	2188	2142	2212	2136	1248	2199
2003	2611	2567	2070	2456	2473	2179	2244	2055	1797	2149	1956	1942	2314	1960	2139	2153	2206	2128	1077	2067
2004	2769	2731	2227	2606	2581	2286	2358	2174	1924	2237	2051	2061	2420	2123	2272	2305	2351	2279	1168	2189
2005	2662	2618	2104	2471	2510	2232	2304	2116	1851	2184	2002	2000	2383	2043	2173	2184	2237	2161	1107	2153
2006	2423	2376	1879	2260	2314	2048	2118	1926	1642	2045	1858	1800	2203	1850	1936	1970	2015	1939	915	1977
2007	2663	2662	2134	2538	2548	2270	2338	2150	1886	2249	2063	2131	2486	2136	2220	2246	2295	2219	1256	2181
2008	2594	2557	2079	2552	2606	2334	2409	2225	1977	2332	2148	2226	2575	2265	2300	2265	2335	2261	1335	2266
2009	2633	2608	2111	2549	2588	2302	2370	2181	1924	2283	2094	2103	2467	2132	2250	2252	2309	2232	1222	2205
2010	2664	2686	2154	2599	2644	2370	2429	2239	1983	2422	2227	2269	2608	2280	2310	2291	2353	2274	1403	2271

Table 21: *Matrix with all the historical (1951-2010) values of the Huglin Index, values over the threshold of 2700 highlighted in red, over the threshold of 3000 in bold red. Legend on Table 22.*

Number	**Location**
1	Cerasuolo di Vittoria DOCG
2	Marsala DOC
3	Etna DOC
4	Primitivo di Manduria DOCG
5	Morellino di Scansano DOCG
6	Bolgheri DOC
7	Brunello di Montalcino DOCG
8	Nobile Montepulciano DOCG
9	Verdicchio DOCG
10	Barolo DOCG
11	Barbera d'Asti DOCG
12	Prosecco DOCG
13	Amarone DOCG
14	Collio DOC
15	Montepulciano d'Abruzzo DOCG
16	Fiano di Avellino DOCG
17	Greco di Tufo DOCG
18	Taurasi DOCG
19	Franciacorta DOCG
20	Chianti DOCG

Table 22: *legend for all the matrix in the appendix with Huglin Index*

[6] Matrix with projected 2.6 Huglin Index values

2.6	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
2011	2493	2468	1957	2390	2423	2178	2238	2046	1784	2269	2075	2084	2441	2116	2086	2079	2139	2066	1212	2107
2012	2751	2742	2217	2619	2637	2378	2440	2250	1993	2435	2243	2311	2655	2311	2319	2317	2376	2300	1441	2298
2013	2758	2741	2224	2632	2658	2390	2461	2271	2004	2389	2202	2246	2621	2238	2327	2334	2389	2314	1378	2316
2014	2735	2726	2216	2714	2770	2489	2557	2365	2099	2516	2321	2339	2702	2349	2424	2427	2486	2411	1479	2397
2015	2605	2519	2052	2469	2459	2189	2260	2080	1852	2195	2016	2139	2444	2203	2170	2152	2218	2148	1220	2118
2016	2601	2598	2068	2432	2526	2257	2320	2127	1853	2290	2098	2103	2466	2126	2158	2146	2203	2124	1229	2170
2017	2640	2610	2099	2480	2501	2227	2288	2099	1835	2252	2060	2085	2447	2076	2160	2147	2206	2130	1229	2132
2018	2741	2721	2216	2703	2790	2536	2598	2402	2116	2606	2414	2424	2798	2426	2404	2379	2441	2364	1563	2461
2019	2722	2685	2164	2538	2577	2297	2370	2183	1907	2251	2068	2090	2472	2116	2234	2254	2305	2228	1199	2220
2020	2701	2659	2168	2570	2632	2366	2432	2238	1958	2381	2193	2226	2595	2228	2264	2289	2337	2258	1354	2284
2021	2821	2782	2279	2730	2765	2491	2565	2378	2099	2439	2256	2275	2675	2279	2412	2413	2470	2398	1391	2420
2022	2802	2760	2269	2662	2760	2473	2552	2359	2065	2384	2205	2222	2619	2251	2358	2359	2411	2334	1322	2399
2023	2712	2681	2178	2581	2650	2372	2437	2247	1985	2408	2216	2284	2622	2277	2299	2279	2340	2261	1418	2278
2024	2872	2838	2351	2807	2860	2568	2642	2453	2182	2536	2348	2362	2736	2388	2502	2511	2565	2490	1479	2479
2025	2752	2753	2217	2636	2670	2374	2445	2256	1989	2308	2124	2170	2525	2198	2332	2356	2406	2327	1281	2274
2026	2805	2784	2279	2645	2697	2436	2496	2303	2038	2521	2328	2420	2749	2403	2353	2378	2428	2349	1562	2348
2027	2758	2753	2232	2674	2730	2461	2522	2333	2078	2542	2350	2469	2781	2445	2392	2369	2434	2357	1608	2371
2028	2752	2686	2219	2679	2626	2347	2419	2240	2016	2303	2123	2232	2553	2297	2358	2355	2417	2348	1312	2266
2029	2663	2671	2150	2557	2652	2377	2436	2240	1961	2407	2211	2204	2574	2209	2274	2296	2345	2262	1349	2274
2030	2724	2700	2222	2732	2730	2445	2514	2330	2092	2456	2267	2357	2684	2370	2427	2398	2466	2394	1477	2354
2031	2848	2805	2326	2789	2758	2470	2545	2359	2086	2437	2253	2290	2664	2307	2432	2467	2513	2443	1413	2391
2032	2564	2535	2028	2478	2482	2192	2253	2067	1822	2177	1988	2025	2362	2062	2161	2150	2210	2135	1143	2078
2033	2738	2716	2202	2623	2726	2464	2529	2339	2068	2478	2294	2380	2725	2389	2357	2307	2378	2301	1496	2389
2034	3005	**3008**	2480	2957	3061	2778	2857	2667	2376	2690	2512	2543	2946	2563	2680	2682	2737	2660	1656	2710
2035	2692	2654	2172	2633	2693	2412	2484	2297	2024	2397	2210	2254	2617	2281	2341	2334	2393	2318	1364	2332
2036	2836	2823	2334	2860	2903	2635	2706	2522	2259	2647	2461	2545	2908	2529	2581	2568	2631	2558	1675	2566
2037	2769	2739	2221	2580	2679	2416	2470	2279	2013	2489	2290	2272	2642	2281	2316	2288	2350	2269	1427	2318
2038	2605	2576	2053	2416	2573	2320	2382	2186	1902	2358	2168	2157	2543	2170	2174	2128	2194	2111	1296	2245
2039	2667	2612	2128	2564	2490	2219	2288	2110	1892	2266	2081	2191	2502	2204	2226	2207	2272	2207	1305	2141
2040	2711	2691	2176	2599	2598	2336	2398	2207	1946	2414	2217	2222	2585	2221	2280	2280	2337	2264	1366	2251
2041	2827	2799	2312	2802	2772	2516	2581	2398	2167	2598	2408	2503	2834	2494	2506	2477	2547	2476	1640	2443
2042	2697	2681	2155	2544	2573	2297	2368	2179	1918	2300	2111	2113	2485	2143	2240	2271	2318	2243	1235	2215
2043	2743	2709	2214	2667	2704	2417	2486	2299	2036	2414	2222	2248	2604	2275	2364	2374	2428	2354	1361	2322
2044	2767	2769	2248	2782	2797	2515	2586	2398	2151	2539	2350	2425	2758	2429	2473	2449	2515	2444	1554	2425
2045	2699	2669	2170	2631	2593	2323	2385	2204	1964	2364	2170	2215	2556	2246	2303	2303	2364	2293	1332	2234
2046	2946	2916	2439	3023	2864	2558	2639	2463	2246	2444	2270	2444	2745	2501	2602	2642	2692	2633	1515	2467
2047	2845	2827	2329	2821	2854	2565	2639	2448	2170	2512	2327	2345	2717	2389	2490	2527	2573	2500	1454	2478
2048	2851	2825	2316	2698	2617	2325	2394	2216	1982	2275	2090	2121	2471	2180	2347	2393	2438	2367	1216	2228
2049	2872	2864	2370	2893	2934	2652	2716	2534	2302	2681	2490	2600	2914	2601	2615	2553	2629	2556	1724	2552
2050	2909	2902	2388	2862	2977	2689	2756	2560	2265	2644	2456	2426	2824	2446	2573	2582	2633	2555	1562	2590
2051	2802	2781	2260	2685	2789	2484	2562	2378	2115	2387	2209	2343	2673	2361	2434	2394	2462	2385	1437	2389
2052	2785	2746	2253	2759	2739	2441	2515	2333	2083	2398	2211	2224	2586	2279	2440	2433	2495	2423	1328	2347
2053	2849	2808	2315	2767	2782	2483	2556	2369	2101	2378	2199	2259	2625	2290	2454	2464	2518	2442	1361	2385
2054	2796	2738	2238	2619	2698	2419	2496	2309	2036	2370	2190	2239	2607	2270	2344	2340	2398	2325	1336	2349

2055	2871	2852	2330	2774	2872	2580	2651	2463	2187	2519	2336	2386	2752	2409	2504	2493	2552	2473	1498	2486
2056	2815	2788	2284	2706	2724	2449	2507	2315	2048	2498	2302	2303	2659	2323	2374	2403	2450	2373	1448	2346
2057	2757	2740	2240	2696	2743	2482	2549	2361	2102	2523	2332	2338	2711	2365	2411	2397	2459	2384	1462	2410
2058	2913	2893	2386	2870	2871	2614	2675	2488	2232	2701	2504	2545	2895	2549	2541	2533	2593	2521	1678	2535
2059	2812	2751	2270	2717	2656	2381	2456	2271	2019	2320	2142	2191	2558	2233	2342	2380	2427	2360	1284	2309
2060	2880	2885	2374	2890	**3019**	2750	2822	2627	2335	2783	2595	2631	**3008**	2627	2638	2598	2667	2589	1766	2682
2061	2651	2620	2111	2467	2585	2303	2363	2170	1890	2337	2139	2083	2463	2112	2201	2194	2250	2167	1223	2197
2062	**3003**	**3021**	2508	**3029**	**3053**	2767	2834	2655	2425	2785	2596	2693	**3024**	2692	2770	2722	2795	2719	1821	2670
2063	2868	2823	2335	2821	2728	2425	2494	2314	2094	2437	2244	2278	2616	2286	2483	2483	2545	2478	1414	2314
2064	2857	2812	2318	2757	2663	2383	2447	2269	2051	2392	2206	2308	2622	2333	2400	2402	2460	2391	1419	2288
2065	2687	2664	2147	2526	2587	2331	2388	2198	1936	2422	2226	2202	2572	2216	2250	2227	2291	2213	1349	2247
2066	2740	2727	2217	2646	2754	2481	2541	2348	2073	2498	2307	2333	2692	2344	2377	2343	2406	2326	1469	2384
2067	2749	2739	2220	2658	2726	2447	2515	2325	2056	2460	2274	2337	2683	2346	2363	2352	2412	2336	1463	2361
2068	2905	2878	2368	2794	2838	2561	2636	2449	2174	2469	2293	2376	2749	2400	2492	2504	2557	2481	1475	2489
2069	2689	2629	2144	2544	2523	2261	2324	2142	1915	2307	2124	2238	2550	2256	2239	2224	2286	2214	1354	2181
2070	2757	2757	2238	2683	2712	2469	2529	2336	2077	2574	2377	2378	2738	2407	2369	2355	2416	2342	1518	2396
2071	2772	2714	2233	2656	2614	2329	2399	2218	1991	2310	2126	2194	2531	2222	2341	2337	2398	2327	1312	2238
2072	2818	2807	2298	2785	2856	2581	2646	2456	2196	2595	2405	2453	2802	2474	2502	2464	2531	2454	1575	2490
2073	2864	2831	2329	2755	2776	2487	2556	2367	2100	2441	2257	2313	2662	2337	2430	2436	2490	2415	1420	2390
2074	2854	2837	2323	2768	2781	2515	2583	2391	2110	2481	2297	2345	2724	2350	2425	2457	2505	2432	1467	2438
2075	2940	2929	2387	2779	2854	2599	2667	2474	2192	2637	2450	2483	2867	2476	2495	2493	2550	2473	1625	2535
2076	2743	2735	2203	2572	2610	2366	2419	2228	1972	2516	2314	2310	2662	2317	2283	2266	2327	2248	1461	2284
2077	2786	2755	2252	2705	2722	2457	2528	2343	2095	2468	2282	2300	2672	2330	2405	2384	2448	2376	1413	2386
2078	2798	2756	2272	2699	2719	2437	2497	2308	2051	2468	2272	2275	2628	2296	2376	2376	2430	2355	1413	2330
2079	2899	2899	2379	2807	2768	2494	2558	2373	2130	2523	2333	2379	2718	2415	2468	2484	2536	2463	1498	2404
2080	2740	2715	2193	2547	2601	2324	2390	2195	1917	2308	2119	2079	2466	2121	2234	2262	2308	2228	1199	2232
2081	2769	2732	2237	2704	2736	2469	2538	2344	2065	2485	2295	2289	2669	2316	2369	2378	2431	2359	1412	2392
2082	2755	2738	2231	2644	2712	2436	2504	2315	2048	2455	2265	2331	2677	2342	2367	2372	2428	2350	1463	2349
2083	2758	2729	2228	2652	2685	2407	2477	2293	2044	2431	2245	2354	2676	2367	2366	2357	2418	2344	1469	2325
2084	2764	2741	2225	2604	2612	2347	2409	2221	1968	2419	2228	2299	2636	2291	2295	2300	2355	2281	1439	2264
2085	2883	2847	2336	2735	2737	2473	2540	2353	2110	2527	2339	2419	2753	2425	2434	2430	2489	2415	1540	2396
2086	2786	2776	2242	2625	2661	2404	2464	2271	2010	2467	2276	2300	2662	2291	2323	2328	2384	2307	1450	2319
2087	2804	2763	2266	2628	2636	2385	2446	2260	2023	2462	2271	2262	2631	2292	2358	2346	2406	2329	1401	2311
2088	2714	2646	2160	2516	2412	2172	2233	2051	1835	2287	2097	2179	2501	2194	2169	2170	2230	2160	1303	2107
2089	2643	2611	2116	2523	2575	2305	2370	2180	1912	2347	2153	2134	2508	2151	2231	2222	2280	2204	1267	2220
2090	2783	2736	2233	2637	2633	2366	2434	2250	2021	2386	2203	2303	2623	2334	2334	2317	2381	2309	1416	2286
2091	2711	2687	2165	2531	2545	2264	2331	2145	1897	2243	2055	2059	2417	2112	2225	2225	2279	2203	1167	2170
2092	2810	2785	2270	2646	2655	2400	2459	2273	2038	2493	2302	2388	2705	2386	2357	2327	2392	2318	1521	2315
2093	2775	2771	2266	2748	2799	2548	2605	2411	2153	2685	2484	2533	2868	2527	2454	2408	2477	2403	1688	2464
2094	2699	2669	2159	2583	2598	2325	2394	2206	1947	2325	2138	2192	2540	2223	2259	2251	2311	2238	1304	2243
2095	2840	2827	2308	2752	2770	2478	2548	2359	2097	2431	2244	2296	2653	2308	2438	2451	2505	2430	1412	2379
2096	2911	2888	2387	2825	2781	2493	2561	2374	2127	2497	2311	2412	2740	2409	2476	2497	2548	2477	1538	2396
2097	2690	2645	2139	2523	2553	2284	2349	2168	1940	2332	2145	2213	2535	2248	2255	2211	2281	2206	1325	2201
2098	2822	2760	2291	2734	2690	2407	2482	2304	2079	2384	2202	2330	2646	2372	2415	2414	2473	2404	1424	2329
2099	2917	2875	2403	2937	2853	2573	2651	2475	2245	2507	2332	2432	2771	2495	2583	2577	2639	2576	1505	2504

Table 23: *matrix with all the projected 2.6 values of the Huglin Index, values over the threshold of 2700 highlighted in red, over the threshold of 3000 in bold red. Legend on Table 22.*

[7] Matrix with projected 6.0 Huglin Index values

6.0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
2011	2722	2686	2196	2663	2666	2392	2463	2276	2026	2371	2186	2269	2618	2283	2349	2343	2403	2333	1384	2310
2012	2590	2574	2065	2478	2579	2298	2363	2174	1905	2256	2069	2118	2478	2138	2209	2188	2250	2168	1230	2202
2013	2672	2651	2156	2670	2670	2388	2457	2276	2045	2433	2242	2352	2665	2370	2384	2338	2412	2340	1476	2300
2014	2752	2725	2228	2649	2682	2398	2458	2271	2012	2453	2254	2262	2612	2264	2348	2347	2403	2326	1407	2292
2015	2639	2599	2107	2567	2609	2345	2403	2212	1951	2471	2264	2231	2600	2223	2269	2235	2303	2226	1395	2252
2016	2610	2597	2074	2528	2532	2256	2317	2128	1872	2282	2090	2129	2474	2149	2192	2184	2242	2168	1254	2158
2017	2622	2575	2075	2458	2471	2209	2275	2091	1859	2301	2109	2161	2485	2200	2174	2138	2207	2134	1283	2132
2018	2682	2658	2140	2584	2681	2425	2488	2296	2029	2524	2329	2385	2731	2370	2325	2282	2351	2273	1530	2349
2019	2732	2665	2187	2613	2597	2306	2380	2198	1945	2229	2049	2100	2463	2142	2285	2301	2354	2282	1194	2219
2020	2646	2621	2113	2566	2629	2341	2404	2212	1943	2367	2171	2146	2515	2157	2273	2268	2325	2248	1291	2235
2021	2776	2764	2266	2755	2779	2505	2567	2379	2123	2570	2371	2361	2732	2357	2458	2446	2508	2432	1521	2409
2022	2711	2684	2173	2614	2574	2299	2365	2183	1945	2304	2119	2223	2541	2251	2279	2285	2343	2273	1328	2212
2023	2749	2725	2227	2704	2686	2402	2467	2282	2042	2417	2227	2297	2626	2314	2389	2384	2445	2372	1424	2302
2024	2603	2543	2046	2394	2415	2140	2205	2017	1757	2147	1956	1960	2326	1981	2084	2092	2146	2069	1085	2050
2025	2732	2706	2202	2625	2585	2310	2379	2196	1953	2329	2141	2192	2529	2244	2283	2296	2350	2279	1301	2228
2026	2766	2739	2223	2591	2692	2431	2498	2306	2028	2479	2288	2314	2684	2325	2326	2328	2382	2303	1451	2359
2027	2657	2616	2127	2552	2580	2294	2362	2176	1924	2312	2120	2175	2510	2191	2247	2230	2291	2218	1301	2198
2028	2730	2708	2184	2555	2644	2374	2432	2235	1950	2425	2226	2213	2589	2206	2255	2253	2306	2226	1364	2275
2029	2721	2700	2201	2597	2664	2401	2463	2271	1998	2472	2275	2256	2632	2256	2309	2298	2356	2277	1396	2317
2030	2725	2678	2176	2592	2541	2271	2340	2155	1909	2283	2096	2145	2489	2189	2236	2262	2313	2244	1248	2193
2031	2648	2637	2104	2539	2549	2299	2362	2173	1917	2357	2167	2145	2525	2168	2222	2195	2260	2188	1279	2229
2032	2708	2671	2167	2572	2568	2291	2363	2179	1936	2285	2100	2202	2529	2227	2267	2253	2315	2242	1306	2211
2033	2562	2517	2013	2436	2392	2124	2186	2004	1784	2183	1994	2097	2398	2127	2120	2104	2167	2095	1208	2033
2034	2863	2854	2339	2773	2866	2598	2673	2481	2211	2559	2379	2448	2814	2466	2506	2509	2565	2487	1552	2531
2035	2702	2675	2167	2593	2590	2315	2387	2203	1952	2252	2073	2133	2490	2187	2278	2288	2344	2269	1225	2237
2036	2682	2637	2143	2550	2477	2204	2269	2082	1836	2207	2021	2077	2416	2106	2184	2224	2271	2201	1185	2113
2037	2702	2679	2164	2547	2620	2351	2423	2230	1955	2322	2139	2152	2529	2198	2257	2273	2324	2245	1258	2280
2038	2921	2884	2395	2830	2840	2551	2615	2429	2178	2552	2362	2437	2777	2428	2519	2524	2579	2504	1577	2445
2039	2858	2817	2334	2784	2769	2504	2566	2378	2123	2538	2346	2331	2711	2348	2454	2487	2537	2464	1475	2417
2040	2788	2745	2249	2662	2644	2388	2451	2261	2007	2471	2280	2326	2673	2333	2331	2353	2405	2332	1468	2313
2041	2801	2773	2267	2710	2706	2425	2495	2307	2050	2438	2245	2227	2603	2258	2393	2413	2466	2394	1351	2337
2042	2756	2733	2225	2660	2713	2446	2509	2320	2058	2488	2295	2316	2673	2357	2371	2367	2425	2348	1441	2361
2043	2847	2820	2315	2749	2867	2620	2682	2481	2179	2691	2496	2476	2870	2486	2458	2474	2524	2444	1625	2550
2044	2747	2726	2202	2584	2653	2401	2460	2262	1974	2462	2271	2278	2662	2246	2273	2283	2335	2256	1436	2321
2045	2901	2862	2370	2815	2817	2533	2615	2426	2152	2485	2305	2347	2717	2383	2464	2491	2539	2471	1446	2466
2046	2912	2910	2394	2863	**3002**	2709	2774	2583	2313	2737	2542	2614	2951	2608	2633	2581	2651	2569	1752	2602
2047	2938	2898	2394	2733	2835	2580	2648	2448	2149	2627	2437	2391	2799	2393	2439	2487	2526	2446	1534	2514
2048	3128	**3095**	2616	**3090**	3124	2848	2927	2733	2445	2787	2608	2651	**3047**	2646	2766	2825	2864	2791	1771	2781
2049	2881	2849	2359	2817	2842	2563	2639	2451	2186	2535	2353	2399	2767	2424	2511	2534	2586	2512	1507	2490
2050	2710	2656	2165	2564	2601	2323	2391	2205	1957	2347	2162	2240	2569	2265	2270	2274	2330	2255	1358	2239
2051	2781	2717	2228	2629	2603	2328	2396	2213	1979	2345	2159	2206	2551	2232	2318	2327	2383	2310	1325	2244
2052	2866	2877	2349	2773	2887	2616	2674	2485	2229	2721	2515	2494	2853	2504	2537	2472	2545	2464	1646	2516
2053	2830	2811	2293	2695	2742	2480	2540	2352	2096	2561	2368	2416	2746	2438	2408	2408	2465	2388	1546	2393
2054	2844	2805	2318	2815	2759	2489	2554	2374	2143	2503	2316	2402	2736	2421	2485	2466	2533	2464	1515	2404

2055	2773	2736	2246	2701	2684	2415	2474	2286	2048	2524	2324	2368	2694	2368	2385	2382	2441	2370	1518	2317
2056	2862	2834	2335	2782	2813	2528	2596	2407	2146	2533	2345	2432	2766	2435	2473	2486	2539	2463	1556	2434
2057	3031	3003	2515	3035	2962	2669	2746	2564	2325	2623	2443	2592	2908	2618	2676	2682	2738	2672	1685	2586
2058	2800	2763	2275	2762	2747	2461	2539	2353	2087	2401	2222	2281	2643	2322	2419	2445	2496	2428	1372	2388
2059	2922	2924	2401	2801	2806	2515	2581	2393	2139	2502	2314	2369	2712	2378	2491	2516	2565	2488	1492	2411
2060	2917	2901	2371	2782	2845	2589	2646	2455	2189	2665	2472	2488	2851	2481	2505	2502	2560	2481	1639	2503
2061	2968	2925	2456	2915	2919	2660	2734	2550	2315	2712	2525	2595	2949	2591	2633	2620	2683	2612	1722	2599
2062	3000	2997	2479	2885	2867	2605	2669	2484	2262	2673	2480	2553	2881	2562	2598	2594	2653	2579	1682	2519
2063	2815	2790	2285	2736	2702	2439	2501	2311	2064	2497	2303	2313	2665	2339	2389	2396	2450	2380	1442	2350
2064	3025	3008	2491	2931	2989	2719	2784	2592	2317	2742	2549	2559	2931	2571	2624	2649	2696	2618	1690	2631
2065	2936	2910	2390	2829	2914	2644	2715	2522	2238	2601	2421	2480	2860	2478	2545	2535	2594	2515	1598	2571
2066	3038	2985	2527	3042	3118	2828	2903	2715	2438	2762	2581	2658	3029	2676	2753	2741	2800	2726	1776	2746
2067	2952	2939	2436	2913	3025	2760	2834	2640	2363	2796	2607	2640	3012	2645	2649	2631	2693	2615	1760	2695
2068	3027	2990	2498	2934	3052	2763	2838	2648	2371	2700	2518	2541	2925	2556	2684	2663	2725	2644	1656	2677
2069	3092	3096	2592	3112	3130	2853	2923	2733	2471	2837	2651	2722	3078	2738	2804	2807	2863	2791	1836	2769
2070	2834	2791	2291	2738	2748	2469	2542	2357	2093	2444	2259	2230	2622	2276	2415	2418	2475	2406	1342	2392
2071	3042	3037	2533	3026	3162	2886	2949	2749	2453	2921	2726	2761	3120	2747	2747	2740	2795	2717	1899	2789
2072	3047	3024	2519	2930	3009	2730	2813	2619	2324	2664	2488	2527	2921	2546	2626	2678	2719	2643	1630	2672
2073	2856	2818	2320	2783	2849	2563	2633	2443	2181	2571	2381	2401	2756	2433	2490	2477	2536	2461	1527	2470
2074	2887	2862	2340	2733	2759	2466	2538	2346	2080	2435	2248	2326	2661	2350	2412	2450	2496	2419	1438	2369
2075	3072	3044	2550	3023	3117	2840	2910	2713	2412	2880	2683	2643	3037	2652	2715	2742	2789	2714	1783	2757
2076	2952	2901	2414	2912	2895	2614	2702	2515	2240	2508	2338	2343	2747	2408	2556	2605	2650	2583	1422	2562
2077	2972	2946	2440	2904	2969	2719	2794	2604	2322	2700	2525	2638	3004	2634	2604	2593	2653	2581	1750	2672
2078	2928	2905	2411	2855	2847	2554	2620	2433	2183	2553	2363	2386	2735	2410	2533	2545	2599	2524	1512	2451
2079	3044	3009	2506	2898	2952	2681	2747	2551	2272	2742	2550	2583	2936	2581	2586	2626	2669	2591	1722	2596
2080	2889	2821	2344	2789	2708	2446	2520	2335	2096	2444	2266	2362	2700	2394	2419	2457	2506	2441	1458	2384
2081	3173	3129	2640	3123	3200	2935	3017	2822	2525	2872	2698	2742	3147	2749	2819	2845	2893	2820	1845	2887
2082	3004	2955	2474	2952	2893	2634	2706	2519	2268	2648	2465	2497	2868	2524	2594	2615	2667	2601	1613	2572
2083	3150	3122	2621	3096	3117	2842	2918	2726	2443	2825	2640	2639	3035	2653	2756	2803	2846	2774	1758	2771
2084	3063	3048	2543	2974	3094	2819	2886	2691	2403	2852	2660	2719	3077	2710	2696	2708	2758	2677	1858	2734
2085	3105	3101	2571	2993	3118	2873	2946	2745	2438	2938	2751	2734	3144	2714	2716	2735	2785	2708	1874	2827
2086	2947	2900	2414	2879	2912	2634	2705	2515	2257	2612	2426	2472	2830	2494	2578	2576	2633	2560	1587	2548
2087	3051	3046	2530	3003	3071	2796	2870	2682	2426	2813	2625	2683	3034	2697	2736	2718	2781	2708	1795	2721
2088	3099	3084	2561	2955	3047	2763	2837	2640	2343	2714	2530	2526	2921	2544	2647	2680	2722	2643	1645	2680
2089	3229	3217	2722	3249	3443	3186	3265	3070	2770	3208	3030	3197	3540	3169	3009	2957	3025	2949	2321	3142
2090	3214	3176	2688	3149	3187	2893	2972	2786	2527	2846	2663	2707	3075	2726	2865	2858	2916	2843	1818	2811
2091	3123	3104	2608	3111	3183	2902	2976	2785	2506	2883	2698	2791	3146	2778	2820	2824	2878	2803	1913	2823
2092	3248	3199	2722	3220	3179	2879	2955	2773	2525	2847	2662	2743	3086	2760	2878	2906	2956	2888	1849	2787
2093	3124	3088	2581	3054	3106	2830	2905	2713	2432	2803	2620	2648	3025	2674	2746	2749	2806	2734	1754	2759
2094	3144	3079	2609	3073	3101	2826	2904	2711	2426	2782	2601	2629	3018	2645	2736	2780	2824	2753	1729	2760
2095	3132	3085	2607	3056	3075	2785	2869	2686	2416	2687	2513	2593	2970	2622	2756	2798	2843	2769	1689	2720
2096	3102	3082	2588	3067	3118	2847	2917	2723	2438	2854	2668	2700	3078	2692	2745	2756	2808	2735	1829	2771
2097	3244	3207	2732	3259	3275	2993	3072	2885	2616	2947	2769	2868	3224	2884	2933	2946	2999	2929	1967	2925
2098	3054	3036	2538	3063	3168	2918	2987	2792	2502	2946	2762	2799	3175	2824	2770	2761	2819	2747	1914	2861
2099	3016	2992	2488	2918	2968	2693	2760	2571	2311	2698	2511	2553	2906	2579	2633	2638	2693	2618	1671	2606

Table 24: *matrix with all the projected 6.0 values of the Huglin Index, values over the threshold of 2700 highlighted in red, over the threshold of 3000 in bold red. Legend on Table 22.*

[8] Matrix with differences between projected 6.0 and 2.6 Huglin Index values

DELTA	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
2011	229	219	239	273	243	214	225	230	242	102	110	185	177	167	263	264	264	267	172	203
2012	-161	-167	-152	-141	-58	-80	-78	-76	-88	-179	-174	-193	-178	-173	-110	-129	-126	-132	-212	-97
2013	-86	-90	-68	37	13	-2	-4	6	41	44	40	106	45	131	57	4	22	26	97	-16
2014	17	-1	11	-66	-88	-91	-99	-94	-87	-64	-68	-77	-90	-85	-75	-80	-83	-84	-73	-106
2015	34	80	56	98	150	156	143	133	99	276	247	93	156	21	99	84	85	78	176	135
2016	9	-1	7	96	6	-1	-3	1	18	-9	-8	26	8	23	34	38	38	45	24	-12
2017	-19	-35	-24	-21	-31	-18	-14	-8	24	49	49	77	37	125	13	-9	1	3	54	0
2018	-59	-63	-76	-119	-109	-111	-110	-106	-86	-82	-85	-38	-67	-56	-79	-97	-90	-91	-33	-111
2019	10	-21	23	75	20	9	10	15	38	-21	-19	11	-9	26	51	47	50	53	-5	-1
2020	-55	-38	-55	-5	-3	-25	-28	-26	-15	-14	-22	-80	-79	-71	8	-21	-11	-10	-64	-50
2021	-45	-18	-13	25	13	14	2	0	24	131	115	86	57	78	46	33	38	33	130	-11
2022	-92	-75	-96	-49	-186	-173	-187	-176	-121	-79	-86	1	-78	0	-79	-75	-68	-61	5	-187
2023	37	44	49	123	37	31	30	35	57	9	10	12	4	37	90	105	105	111	6	24
2024	-269	-295	-305	-412	-445	-427	-438	-436	-425	-389	-392	-402	-409	-407	-419	-420	-419	-421	-394	-430
2025	-20	-47	-15	-10	-86	-63	-66	-60	-37	21	16	21	4	46	-49	-60	-56	-49	20	-46
2026	-39	-45	-56	-54	-5	-6	2	3	-10	-42	-40	-106	-65	-78	-27	-50	-45	-46	-111	12
2027	-101	-137	-105	-122	-149	-166	-160	-156	-153	-230	-230	-294	-271	-254	-145	-139	-143	-139	-307	-173
2028	-22	22	-35	-124	18	27	13	-5	-66	123	103	-19	35	-90	-103	-102	-111	-123	52	9
2029	58	30	51	40	12	24	27	31	37	65	64	51	58	47	35	2	11	15	47	43
2030	1	-22	-46	-140	-190	-174	-175	-175	-183	-172	-172	-213	-195	-181	-190	-136	-152	-150	-229	-161
2031	-201	-168	-221	-250	-209	-171	-182	-185	-170	-80	-86	-145	-139	-139	-209	-271	-253	-255	-133	-162
2032	144	136	139	94	86	98	109	112	114	107	112	177	168	165	106	104	104	107	163	133
2033	-176	-199	-189	-187	-334	-340	-343	-335	-284	-295	-300	-284	-327	-263	-237	-204	-211	-206	-289	-356
2034	-141	-154	-141	-184	-195	-179	-184	-185	-166	-131	-133	-95	-132	-97	-175	-174	-171	-174	-103	-179
2035	10	21	-5	-40	-103	-97	-97	-95	-73	-145	-138	-121	-126	-94	-62	-45	-49	-49	-139	-95
2036	-154	-187	-191	-310	-425	-432	-437	-440	-423	-440	-441	-468	-492	-423	-396	-344	-359	-357	-490	-453
2037	-67	-60	-57	-33	-59	-65	-47	-49	-58	-167	-151	-121	-113	-84	-60	-15	-26	-23	-169	-39
2038	316	308	342	414	267	231	233	243	275	194	194	280	234	258	345	395	385	393	281	200
2039	191	205	206	220	279	285	278	268	232	272	265	140	209	144	228	280	265	256	170	277
2040	77	54	74	62	46	52	54	54	61	57	64	103	88	112	51	73	67	69	102	62
2041	-26	-25	-45	-91	-67	-91	-86	-90	-117	-160	-163	-275	-231	-237	-113	-65	-81	-83	-290	-106
2042	59	52	70	115	139	149	141	141	141	188	184	204	188	214	130	97	107	105	205	146
2043	104	111	101	83	163	203	197	183	143	277	274	229	266	211	95	100	95	90	264	228
2044	-20	-42	-46	-197	-144	-115	-126	-136	-177	-77	-80	-147	-96	-183	-201	-166	-180	-187	-118	-104
2045	202	193	200	184	224	211	229	222	188	122	135	132	161	137	161	188	175	178	114	232
2046	-34	-6	-45	-160	138	151	135	120	67	293	272	170	205	107	31	-61	-41	-64	237	135
2047	93	70	65	-88	-19	15	9	-1	-22	115	110	46	82	4	-51	-40	-47	-54	80	36
2048	276	270	299	391	507	524	532	518	462	512	519	530	575	467	419	432	426	424	554	553
2049	9	-16	-12	-77	-92	-89	-77	-83	-116	-146	-138	-201	-147	-177	-103	-19	-43	-45	-217	-62
2050	-199	-246	-223	-297	-377	-365	-365	-355	-308	-297	-294	-187	-255	-181	-303	-309	-303	-301	-203	-351
2051	-21	-63	-31	-56	-186	-157	-165	-164	-136	-43	-50	-137	-122	-129	-116	-68	-79	-75	-112	-146
2052	81	131	96	14	148	175	159	152	146	323	304	269	268	225	98	39	51	41	318	169
2053	-19	3	-22	-73	-40	-4	-16	-17	-6	183	169	157	122	149	-46	-56	-53	-54	185	8
2054	47	67	80	196	61	69	58	65	107	133	126	163	129	152	142	126	134	138	179	55

2055	-98	-116	-84	-73	-187	-165	-176	-177	-139	5	-12	-19	-58	-41	-119	-111	-111	-104	20	-170
2056	47	47	51	76	89	79	89	92	98	35	43	128	107	112	99	83	88	90	109	88
2057	274	263	275	339	219	187	197	203	224	100	111	254	197	253	265	284	279	289	223	176
2058	-113	-129	-110	-108	-124	-154	-136	-135	-146	-300	-282	-265	-252	-227	-122	-88	-97	-94	-306	-147
2059	110	173	130	84	151	133	125	122	120	181	172	178	155	145	148	137	139	128	208	102
2060	38	16	-3	-108	-174	-162	-175	-172	-147	-118	-123	-144	-158	-146	-133	-96	-108	-107	-127	-179
2061	317	305	345	448	334	357	371	381	425	375	386	512	486	479	432	426	433	445	499	402
2062	-2	-24	-30	-144	-186	-162	-164	-170	-162	-112	-116	-140	-143	-131	-173	-128	-142	-140	-139	-151
2063	-53	-33	-50	-85	-26	14	7	-3	-29	60	59	36	50	53	-94	-88	-95	-97	28	36
2064	168	196	174	174	327	336	336	323	266	351	343	251	309	238	224	247	235	227	271	343
2065	249	246	242	303	326	313	326	323	302	179	195	278	288	262	295	308	303	302	249	324
2066	298	259	309	396	364	346	362	367	365	265	274	326	337	331	377	398	394	400	307	363
2067	203	200	216	255	299	313	319	315	307	336	333	303	329	299	286	279	281	279	297	334
2068	122	111	129	140	214	201	202	199	197	231	225	165	175	156	192	159	167	163	182	188
2069	403	467	448	568	606	592	598	592	556	530	526	484	528	481	564	583	577	577	482	589
2070	77	34	53	55	37	0	13	22	16	-130	-118	-148	-117	-131	46	63	59	64	-176	-4
2071	270	323	300	370	548	557	550	531	462	611	600	567	589	525	406	402	397	389	587	551
2072	229	217	221	145	153	150	167	163	128	69	83	75	119	72	124	214	189	189	55	182
2073	-7	-13	-9	29	73	76	76	77	81	130	125	89	95	96	60	41	46	46	107	79
2074	34	24	17	-35	-21	-48	-44	-45	-31	-46	-49	-19	-63	0	-13	-7	-9	-13	-30	-69
2075	133	116	163	244	263	241	244	239	219	243	233	161	170	175	220	249	239	240	158	222
2076	208	166	212	340	285	248	282	287	267	-8	24	33	85	92	273	339	323	335	-39	278
2077	186	191	188	199	247	262	266	261	228	232	244	338	333	304	199	210	205	205	337	286
2078	129	149	139	156	128	117	123	126	132	84	91	110	106	114	156	169	168	169	99	121
2079	145	110	127	91	184	187	189	178	143	219	216	205	218	166	119	142	133	127	225	192
2080	149	107	151	242	107	123	130	140	179	136	147	283	234	273	185	195	198	213	259	152
2081	404	397	404	419	464	466	479	478	460	387	403	453	477	433	450	467	462	461	432	495
2082	249	218	244	308	180	197	202	204	220	193	201	166	191	182	227	243	240	250	151	223
2083	392	394	393	444	432	435	441	433	399	395	394	285	359	287	390	446	428	430	289	446
2084	298	307	318	371	482	473	477	469	434	432	432	421	441	419	401	409	403	396	419	470
2085	223	254	235	258	381	399	406	392	329	410	412	316	392	289	283	305	296	293	334	431
2086	161	124	172	254	250	230	241	244	247	145	151	171	169	203	254	247	249	254	137	229
2087	247	283	265	375	435	412	424	422	403	351	354	421	403	405	378	372	375	379	394	411
2088	385	437	401	439	636	591	604	589	508	427	433	347	421	350	478	510	493	484	342	573
2089	585	606	606	726	867	881	895	890	858	860	877	1063	1032	1018	778	735	745	746	1054	922
2090	431	440	455	512	554	527	538	536	506	460	461	404	452	392	531	541	536	534	402	525
2091	412	417	443	580	638	638	645	639	609	640	643	731	729	667	594	599	599	600	747	653
2092	438	414	452	574	524	479	496	500	487	354	359	356	381	374	521	579	564	570	328	472
2093	349	317	316	305	306	282	300	302	279	118	136	115	157	147	292	341	329	332	66	295
2094	445	410	450	490	503	501	509	506	479	457	462	437	478	421	478	529	514	515	425	517
2095	292	258	299	303	306	307	322	326	320	256	269	297	317	314	317	346	338	339	277	341
2096	191	194	200	242	337	355	355	349	311	357	357	288	338	282	269	259	260	259	291	374
2097	554	562	593	735	723	709	723	717	676	614	624	655	689	636	678	735	717	723	642	723
2098	232	277	247	329	478	511	505	488	422	562	559	469	529	452	356	347	347	343	490	532
2099	99	117	85	-19	115	121	109	96	66	191	179	121	135	84	50	61	54	42	166	102

Table 25: *matrix with all the projected differences between 6.0 and 2.6 values of the Huglin Index.Legend on Table 22.*