Vino Vini Viti

Climate Change Impacts and Adaptations for Small Wine Producers in Central Italy

Figure I : Pacina winery view. (Pacina, 2020).

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Acknowledgements

This thesis has been a product of collaboration between people who share a common vision. It is about the importance of preserving one's roots and passions, while at the same time respecting nature and culture but also being able to adapt, develop and progress.

I'd firstly like to thank Dr. Murray Scown, my supervisor, who supported me throughout this process. I am honoured to have had him guide me throughout this journey. Without his eternal patience, comprehension and teachings, this thesis would not be what it is. Thank you is not enough.

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I would like to thank Polidori winery, one of the first organic wineries to be set up in Italy. Thank you for setting such an important example for how we need to move forward: not always utilizing artificial chemicals but instead working with nature, side-by-side, to obtain spectacular products.

This thesis is dedicated to my family, for the never-ending support and love of my parents and sister. But particularly to the older generation who have taught me to always remember where I come from and to never forget my roots. And also to the next generation: to Sophia and Matteo, in the hope they will follow their heart and passions.

In vino veritas.

Abstract

Climate change is a global challenge, affecting the everyday lives of people as well as sectors globally. In particular, changing temperatures and climates have a profound effect on the food sector. Wine, for example, is especially touched as it has a specific climate niche for growth and maturation of grapes.

This research assesses the impacts of climate change on viticulture and possible adaptation strategies that wineries can implement. Numerous studies have been conducted to comprehend the intrinsic nature of wine and climate. However, not many studies focused on a local scale to understand adaptation strategies and how small wineries may be affected.

The thesis focuses on two wineries in Italy: Pacina in Tuscany and Polidori in Umbria. The two can be considered similar in that they are found in hilly areas, produce organic wines, respect surrounding nature, and have minimal intervention strategies for cultivation and winemaking.

The effects of summer maximum temperatures are studied to see how they affect the grape ratio of sugar and pH, meanwhile seeing how future projections of RCP 4.5 and RCP 8.5 may have an effect on wine. Lastly, possible adaptation strategies are assessed.

Through the interviews, both wineries have seen changes in phenological phases, specifically when it comes to maturation and harvesting. During the last decades, the timing of the grapes ripening and harvesting have shifted forward. Increases in temperature have led to grapes containing more sugars, causing an increase in alcohol percentage in the wine. However, both wineries have been able to maintain complexity within the wine, therefore no significant alterations to the taste and quality. This latest finding is in contrast to what is usually described in the literature.

There are different solutions that the wineries can implement which require little to no intervention for adaptation strategies. These solutions are in line with their nature-based ethos. A solution is to adopt blending of grape varieties when producing wine. Another one, which Pacina winery is interested in, is to assess what else can be planted alongside the grapevines. This is to, in part, expand their product range and therefore expand their business strategy and offering. Polidori would like to see change on a governmental level.

In conclusion, there is no doubt that climate change is affecting these wineries. Adaptation strategies are needed that will not only allow these wineries to

continue to product their wine, but that allow them to remain in line with the ethics and beliefs of winery.

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List of Abbreviations

ALADIN - Centre National de Recherces Météorologiques

AOC – Appellation d'Origine Contrôlée

CMCC - Centro EuroMediterraneo sui Cambiamenti Climatici

DOC – Denominazione di Origine Controllata

DOCG – Denominazione di Origine Controllata e Garantita

GUF - Goethe University Frankfurt

IGP – Indicazione Geografica Protetta

LMD - Laboratoire de Météorologie Dynamique

RCP – Representative Concentration Pathway

1. Introduction

1.1 Wine: History, Culture and Economy

Louis Pasteur stated, "the flavour of wine is like delicate poetry" (McGovern, 2009). This idea of wine romanticism has existed for centuries, due to the qualities and taste of it. Wine has a long history within different countries and cultures. It was present during the rise of empires, the birth of scientific discoveries, and the creation of works of art.

Wine grapes (*Vitis vinifera*) were domesticated within the Middle East (Aversano et al., 2017; McGovern, 2009). It is one of the oldest cultivated horticultural crops (Cook & Wolkovich, 2016; Jones, 2003; Jones et al., 2005). According to Toth and Gald (2014), the world is divided into the Old Wine World (Italy, Spain and France) and the New Wine World (where the production of wine did not exist prior to European colonization).

Wine is not a necessity for human survival, rather a commodity with large cultural value and heritage, especially throughout Europe (Mozell and Tchach, 2014; Santillan et al., 2019). The first signs in Italy of wine were between the 9th and 7th century BC (Aversano et al., 2017). For the Romans, wine was of great importance. They knew the differences between qualities of wine and the regions where the best wines were produced. It is clear that the quality and taste of wine has been important and has developed over the years. During the mid 16th Century there were four wine tastes: "*acute, austere, middle and sweet"* (Shapin, 2012). It was also at this time that we started to understand the effect climate has on the taste of wine.

The current international wine industry owes its creation to France in the early 19th century as this is when they began to establish ways to assess the quality of wine. There were differences between wine consumed by locals and wine used for exports and trade (Mocarelli & Vaquero Piñeiro, 2019). There was a large disparity in the 19th century of exported wine between Italy and France.

1.2 Wine History in Italy

Wine is important for the culture and economy of Italy. It has been part of Italian culture for millennia, heading further back than ancient Rome. It is a fundamental part of Italian culture. In the 20th century, the production of quality Italian wine increased significantly. Italy became the first global producer (Messina et al., 2019). In 1960, Italy created a specific appellation system for wines with four hierarchical categories, these are the following in ascending order: Vino da Tavola, IGT, DOC, DOCG (Geçer & Yerlikaya, 2018). DOCG was

created in 1963 for the utmost distinguished wines: Barolo, Barbaresco, Chianti, Brunello di Montalcino and Vino Nobile di Montepulciano. Currently, around 20 wines have this appellation.

Throughout the different published literature in the 18th century, it is clear that there was a trend in trying to comprehend wine and grapes, as well as the challenges to harvesting it (Mocarelli & Vaquero Piñeiro, 2019). The book "A history of Wine in Europe"(Messina et al., 2019) discusses the evolution of wine within Central Italy, and how it came to be famous (this will be discussed in the next paragraph). For example, Tuscany is currently known to produce prestigious wine, however, this was not always the case.

Wine from central Italy was known to not be of adequate quality, as there was insufficient knowledge surrounding winemaking and it was tailored to local taste. A common agricultural practice in the two regions was "*alberate*" or "*maritate*" where trees were used to support vines, which inhibited the maturation of the grapes. The harvesting of different grape varieties at different times was unknown then. Grapes were all harvested at the same time, mixed in the same vessels leading to imbalanced wines. It is important to note that the bad quality of wine was not purely a factor of grapes and poor wine making practice, but of social origin. During that time, land was divided among various people (sharecropping) and producing large quantities was important. This led to the peasants not taking much care in creating wine of good quality with the master's grape.

The "*renaissance*" of wine within central Italy occurred in the later decades of the 19th century. Baron Bettino Ricasoli, Prime Minister of Italy for four years, supported the modernization of agriculture and ensured that wine was of quality to be exported. He created a laboratory of oenology to make Chianti, which he claimed was the "*true perfect wine*". In the 20th century, Tuscany became renowned for wine. Umbria then quickly followed using the new Tuscan wine method. This demonstrates the importance of the origin of wine within the two regions, which are used in the research of this thesis.

Italy currently produces the biggest amount of wine globally, and over 30% of the total EU's volume (Di Carlo, et al., 2019; Saccelli et al., 2016). Grapes are one of the most important crops for economic activities (Marta et al., 2010). Italy has over 2000 endemic varieties, making it one of the most prominent international producers of varieties in the world (Gecer and Yerlikaya, 2018; Morales-Castilla et al., 2020). Grape production therefore produces economic and social benefits – from its export, to rural income, and even tourism. It also creates, to a certain extent, environmental benefits. Vineyards, in comparison to other crops, utilize fewer water and carbon dioxide production (Santillan et al., 2019).

1.2 Wine Variety, Chemistry and Quality

A grape's chemical composition is dependent on a number of factors, such as soil quality, cultural practices, climate, water, and the wine makers themselves (Ferrer-Gallego et al., 2012). Wine grape varieties have specific climate niches which lead to ideal production and quality measures. This means that grapes are at large risk from short-term variability in climate and longer-term change (Mozell and Thach, 2014). Climate has and will always have an effect on grapes. Figure 1 demonstrates the temperature and ranges at which different grape varieties reach optimum maturity levels. For example, *Chardonnay* has a large average range in *Growing Season Temperature* from 13°C-17°C, compared to *Viognier*, ranging from approximately 17°C-19°C. This emphasizes the interdependence between climate and temperature for grapes. Interestingly, Figure 1 illustrates that, on average, white wine varieties require lower temperature niches than red wine varieties.

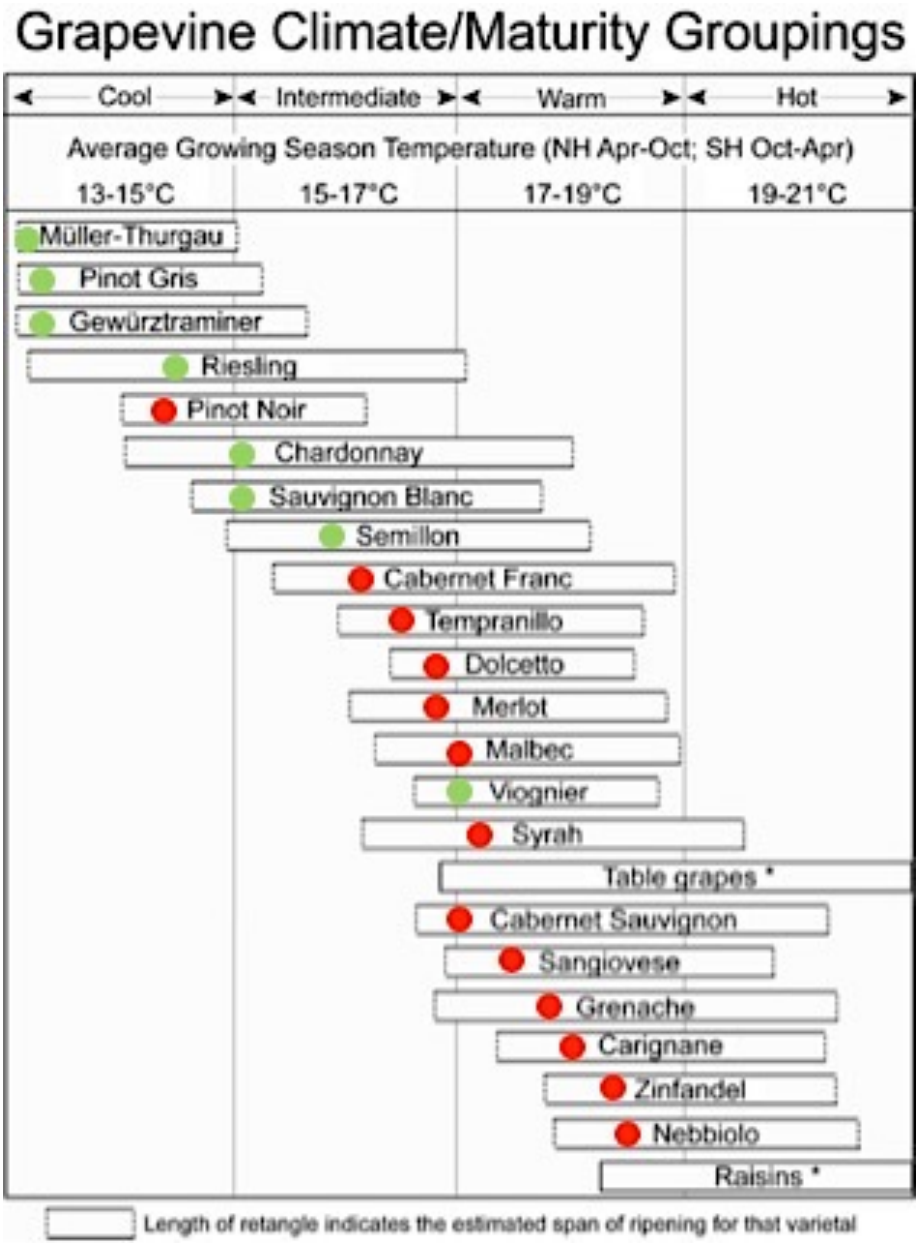

Fig. 1. Grapevine maturity groupings of high quality wines derived from the nexus of requirements of the phenology and the seasonal growth mean temperatures (reproduced from Jones et al., 2006; Jones et al., 2012). The green circle demonstrates white grapes, while the red circle denotes red grapes.

According to various scholars, temperature affects grape quality, vegetative cycles and has a strong relation with vine phenology (the physiological reaction to climate) (de Orduna, 2010; Parker et al., 2013; van Leeuwen and Darriet, 2014). Phenological phases are the different stages within grape development (figure 2). The core stages are: *bud break, flowering, veraison and ripening* (Jones and Davis, 2000; Moriondo et al., 2011; Salinger et al., 2015). Bud break refers to where the plant shoot grows from a branch after the dormant winter period, and forms new green tissue. Following this, flowering guarantees fertilization and

commences the development of the grape. Lastly, veraison is the beginning of grape ripening, which ends once harvested. The veraison stage is very delicate and fragile as the grape experiences the biggest change during this period (Duchene et al., 2010). This final step defines the wine variation and balance between acidity and sugar concentrations.

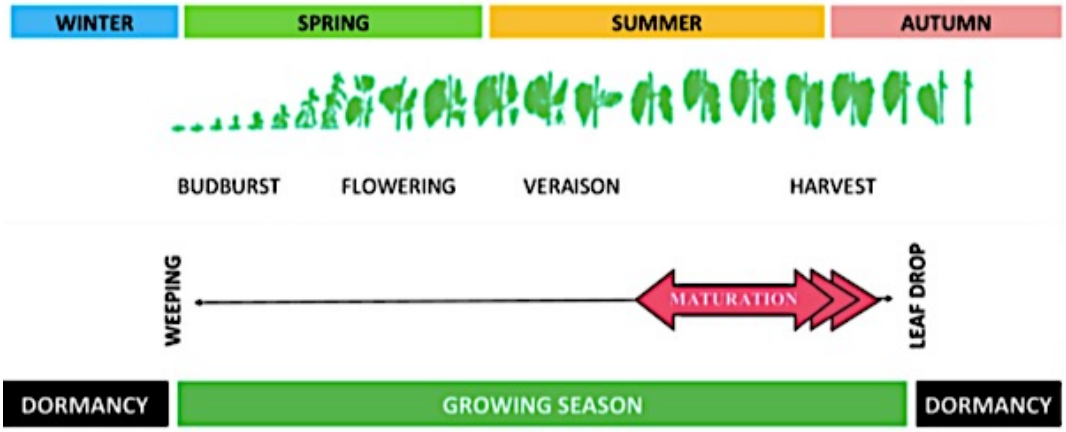

Fig. 2. Phenological phase of vines (reproduced from Santos et al., 2020)

Trends suggest that the phenological stages of wine grapes are changing. Developmental stages are beginning earlier, causing a decrease in growing cycle times, overall yields and biomass collections (de Orduna, 2010; Moriondo et al., 2011). The number of days between different phenological events are decreasing as a result of warmer temperatures. Studies have shown that an increase in temperature of just 1^{o}C has caused an advancement of 5-10 days between different stages (Jones, 2012; Santos et al., 2020). Moreover, when temperatures are higher than normal, grapes do not develop correctly, resulting in imbalanced flavours and higher alcohol percentages (Jones, 2012; Santos et al., 2020).

Viticulture is known as the cultivation of grapes, and it is susceptible to climate alterations. In fact, changes in wine production and quality have been used in the past to confirm when there have been changes in climate (di Lena et al., 2019; Hannah et al., 2013). Terroir is known as the differences in temperature, soils and precipitation, with seasonal temperatures delimiting the particular cultivated wine grape in the region (Bernetti et al., 2012; Cogato et al., 2019). Inter-annual climate variability also establishes the vintage-to-vintage of a wine (Green, 2018). These are two important factors that ensure the individuality of a wine; due to the regional and temporal variation.

Wine taste and quality is dependent on multiple factors, such as polyphenolic compounds (Coletta et al., 2014). High quality wines emerge from higher mean temperatures and lower mean precipitation (Salinger et al., 2015). Levels of certain chemicals found within grapes are lower with higher temperatures, such

as anthocyanin (Kyraleou et al., 2016). The colour of the wine is determined from the anthocyanin pigments that are found within the skin of the grape. There are five anthocyanin: cyanin, delphin, malvin, peonin and petunin. The more stable the anthocyanin, the richer and more stable the colour (D'Agata, 2014). Tannins that are found in both the skin and in the seeds create bitterness and astringency within the wine. The fingerprint of a wine can be said to be its anthocyanin composition and ratio.

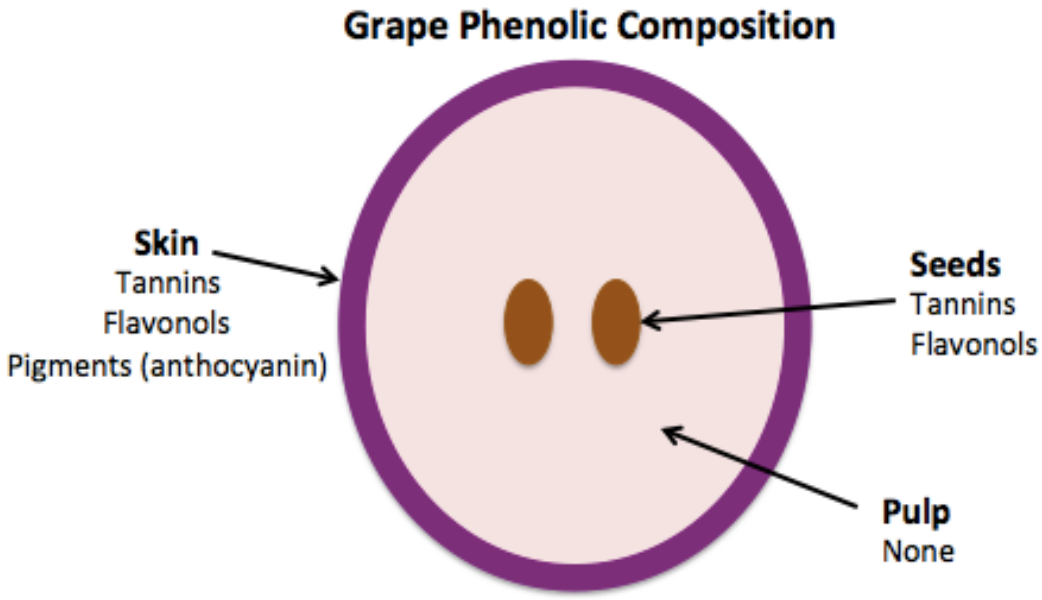

Fig. 3. Grape composition, to demonstrate the different phenolic compounds found within the berry. Authors creation (reference from Adams, 2006).

An increase in temperature, specifically in white wines, causes a decrease in malic acid that ensures microbial stability and increases mouth feel. Consequently, wineries are forced to add tartaric acid to counter these effects (de Orduna, 2010, Keller, 2010). Tartaric acid is the main acid found in grapes, and remains relatively stable when it comes to changes in temperature. de Orduna (2010) found that in temperatures above 30°C, there is a decrease in biomass and surface area of the grape and when maturation occurs there is a decrease in organic acids and an increase in phenolic compounds, sugars, amino acids, and potassium. Astringency, bitterness and the colour of wine are determined by phenolic compounds (Rinaldi et al., 2020; Teixeira et al., 2013). Higher temperatures also create an overripe grape with higher sugar content, less acidity, and lower concentrations of flavonoids and anthocyanins, while creating a wine with higher alcohol and cooked flavours (Mosedale et al., 2016; Mozell and Tchach, 2014). However, if there are extreme temperatures, for example higher than 40 - 45°C, this can hinder certain processes and potentially cause permanent damage to the grape (Malheiro et al., 2010).

1.3 Climate effect on grapes

There is broad scientific consensus that even small changes in climatic conditions can transform the flavour and quality of wine (di Lena, et al., 2019; Jones et al., 2005; Santillan et al., 2019; Zhu et al., 2016). Changes in seasonal temperature cause changes in grape chemistry, creating an excellent wine from a previously poor one, and vice versa. The Mediterranean region is known to be an area that is at high risk of being impacted by climate change and as a consequence so is Italy and Italian wines (Coppola and Giorgi, 2010).

Climate change can have both positive and negative effects on wine production. In the near future, due to the Northern shift, areas that did not have the right abiotic (non living) factors will be able to produce different and more prestigious varieties of wine (Battaglini et al., 2009). For example, the South of England has been able to begin to cultivate wine. The south of The Netherlands has also only been able to cultivate and produce red wine in recent years (Malheiro et al., 2010). From 1950-1999, in the growing season in wine producing areas, there has been an increase in temperature globally of 1.26°C, and from 1950 to 2004 in Europe of 1.7°C (Malheiro et al., 2010; Pallotti et al., 2014). Some have argued that by 2050 it might be impossible to grow grapes in France, Italy and Greece. A clear possibility seeing as the last 55 years have shown notable warming in grape growing areas (Mozell and Tchach, 2014; Schultz and Stoll, 2010).

In recent years, as a result of climate change in many places around the world, such as California and the Mediterranean, there has been a rise in sugar content in grapes. This leads to an increase in alcohol percentage, meaning that wine will not age correctly (Jones, 2012; Kutyna et al., 2010; Garcia-Martin et al., 2010). Heat is a significant factor for the increase of sugar concentration found within the grapes, thus the summer season (ranging from July to September) is a crucial season in wine production (Di Lena, 2018). For a good balanced wine, there needs to be relatively high temperatures in the summer during the day and then cool temperatures at night. This will produce the correct anthocyanin synthesis (Malheiro et al., 2010). Hot days can break down acids quicker, augmenting the sugar concentration and creating elevated alcohol levels within the wine (Salinger et al., 2015). Moreover, lower than average temperatures at night cause more phenolic compounds. These compounds ensure wine quality (Kyrleou et al., 2016). A lack of rainy days and lower daily rainfall causes an increase in flavour concentration (Salinger et al., 2015). During the start of the growing period, the grapevine is heavily reliant upon precipitation. However, later, during the flowering and maturation stage, the grape requires dry periods (Merloni et al., 2018).

As explained above, it is clear that grapevines are one of the most affected crops by climate change due to their dependence on climate. For this reason, they have been identified as a bio-indicator for global warming (Biasi et al., 2019; Cook and Wolkovich, 2016; Fila et al., 2014; Galbreath, 2011; Hannah et al., 2013; Malheiro et al., 2010; Marta et al., 2010).

1.4. Wineries' Adaptation to Climate Change

The risks caused by climate change evolve and continuously escalate. It is imperative to understand and explore possible transitions and adaptation strategies for those people and businesses who rely on a certain climate (Santillan et al., 2019). Adaptation measures may depend on the current diversity in the business model of the winery. This is because there are differences in regionality causing climate change to have different impacts on business (Galbreath, 2011). Furthermore, it is easier for a winery to adapt and survive a changing climate if it cultivates a variety of grapes or crops as opposed to just one variety. This will depend on whether the winery only sells wine or also other products derived (or not) from grapes. Examples include grape diversity and diversification outside of wine including having an agritourism or even selling different types of local products such as olive oil and grains.

Although there is still a lot of uncertainty around the influence of climate change on agro-ecosystems (Bernetti et al., 2012), a number of adaptation strategies for wineries have already been identified. For example, a winery in New Zealand chose a number of adaptation strategies including planting different varieties that could withstand hotter temperatures, buying land higher in altitude, installing water drip lines under the surface and within the soil, recycling and reusing water, alongside many other practices (Galbreath, 2011). Adaptation outside wine production can be that of planting different crops, and having the grape as a complementary crop (if the climate allows cultivation), thus changing business plans (Lereboullet et al., 2013).

1.5 Research Problem/problem formulation and thesis contribution

There is unanimous consensus within academia that climate change is occurring, with countless negative effects on the environment and ecosystems having been observed over the years (Duchene et al., 2010, IPCC, 2014). Worldwide, there has been an increase in average temperature of 1°C since pre-industrial time (CMCC, 2020). Shifts in weather and climate will mean that there will be changes on viticulture, grape quality, and consequently on the wine industry (Cogato et al., 2019; Mozell and Tchach, 2014). Climate change has caused advancement in the phenology of grapevines, altering wine quality and composition of grapes (Fila et

al., 2014; Ortega-Farias and Riveros-Burgos, 2019). In some cases, optimum conditions to produce high quality wine have been met due to changes in climate. However, this could lead to a so-called tipping point, where current quality wine will no longer exist as established grapevines are at risk, such as the ones explored in this thesis (Fila et al., 2014; Green, 2016; Jones et al., 2005). Thus, it is important to understand the changes that have occurred, and to further understand the future challenges that will happen in the wine industry more broadly and what potential adaptation strategies exist.

Research has tended to be conducted on larger, well-renowned wineries and grape varieties. Researchers often study the potential shifts of the optimum cultivation areas to higher latitudes (Sacchelli et al., 2016). While the Tuscan region of Italy has received some attention when it comes to research, little of it has been conducted in the Umbria region of Italy. This thesis intends to contribute to the science on wine and climate change by comprehending the climatic effects on small-scale wineries and to further understand the loss that will occur. There is a large research gap around how small-scale producers might be affected by climate change, and how different effects across grape varieties may be significant to adaptation strategies taken by wineries. The smaller the size a company the more important it is to develop proactive environmental strategies, and the easier it is for them to adapt in comparison to larger companies (Gentilucci et al., 2020; Merloni et al., 2018).

In addition to the above, this thesis will contribute to the discussion around the societal dimension linking climate change and wine. On a societal level, wine is of significant cultural and economic importance. This thesis contributes to the societal dimension by understanding how small scale wineries will be affected by climate change, as this will undoubtedly have an effect on not only their subsistence but also on cultural aspects of wine within Tuscany and Umbria. The focus of this research is on smaller scale producers cultivating different varieties of red and white grapes. As this research will ultimately help inform them of different wine strategies to adapt to changes it is directly relevant for wine producers and it direct.

Culture, roots and regionalism are fiercely felt by Italian people. Only in 1861 did the Italian Kingdom come to be, and Italy therefore became a nation as a whole. This is why Italians firstly feel to be from their region – be it Lazio or Tuscany or Umbria – and then Italian. This notion of regional identity and traditions is strong and linked to specific products, recipes and dialects. This is why autochthonous grapes, which make traditional wines, bring Italians back to their roots (D'Agata, 2014). And it is also one of the reasons for having chosen to study Italian wines in this thesis. The awareness and curiosity within Italy, of how a specific native grape and therefore wine, such as a Passerina, should taste like is

growing (D'Agata, 2014). One must also not forget the connection between Italy and religion, where wine is seen as a symbol for Catholics, and holds an important value to it (Ascione et al., 2020).

1.6. Objective and research questions

1.6.1 Research Aim

The aim of this research is to understand and quantify the potential effects of climate change on future viticulture and identify adaptation options across two regions in Italy: Tuscany and Umbria. The two wineries with whom this thesis is in collaboration with, Pacina and Polidori, are relatively small scale and produce organic wine. They are both largely focussing on the sustainability and naturalistic aspect of the wine and winemaking, trying to intervene as little as possible during the lifetime of the grapevine.

The research aim will be addressed by analysing past trends in climate and grape chemistry, projecting future climate scenarios in these areas, and by interviewing the wine makers, while also demonstrating different adaptation strategies.

The aim will be addressed through the following three research questions, each with their own sub-questions:

1.6.2 Research Questions

1. How has climate change in recent years affected wine chemistry in these wineries?
    a. What are the differences between wines?
2. How might different climate scenarios affect grapes and wine in these regions in the future?
3. What adaptation strategies can be put in place by the wineries?
    a. Are there adaptation options available that do not involve the production of wine?

2. Methodology

2.1 Study areas

The Italian climate is very diverse, ranging from a cold climate in the North and semi-arid climate in the South. It is also important to note that the Italian territory has many mountains and hills, further affecting the climate. The total vineyard area in Italy in 2016 was 656 thousand hectares; around five times the size of Rome, or 66 times the size of Utrecht (Schimmenti et al., 2016).

This study will focus on two organic wineries found in traditional grape-wine growing areas in Central Italy. The wineries are Pacina in Tuscany and Polidori in Umbria. They are found across two adjacent regions (Figure 4). They have been chosen due to their difference in business models, grape cultivation styles, and vinification process. The wineries that participated in this research are considered micro businesses by the European Commission (2020) as they employ less than 10 people, compared to a small business that is classified as less than 50 people (European Commission, 2020). The two wineries also have similarities. Both Pacina winery and Polidori winery are family owned micro business organic wineries. Pacina does have more diversification in the products sold and in its business approach.

Tuscany has been known for centuries for its quality wines, especially for the red wine (Moriondo et al., 2011; Salinger et al., 2015). The cultivation and production of the Chianti wine dates back to the 13th Century (Salinger et al., 2015). The Chianti area within Tuscany is showing an earlier shift in grape ripening, causing change in varieties (Mozell and Tchach, 2014). Umbria on the other hand is known as the “green heart of Italy” (Ascione et al., 2020). In figure 4, it can be seen where the different wineries are. They are found at a distance from of about 100km from each other.

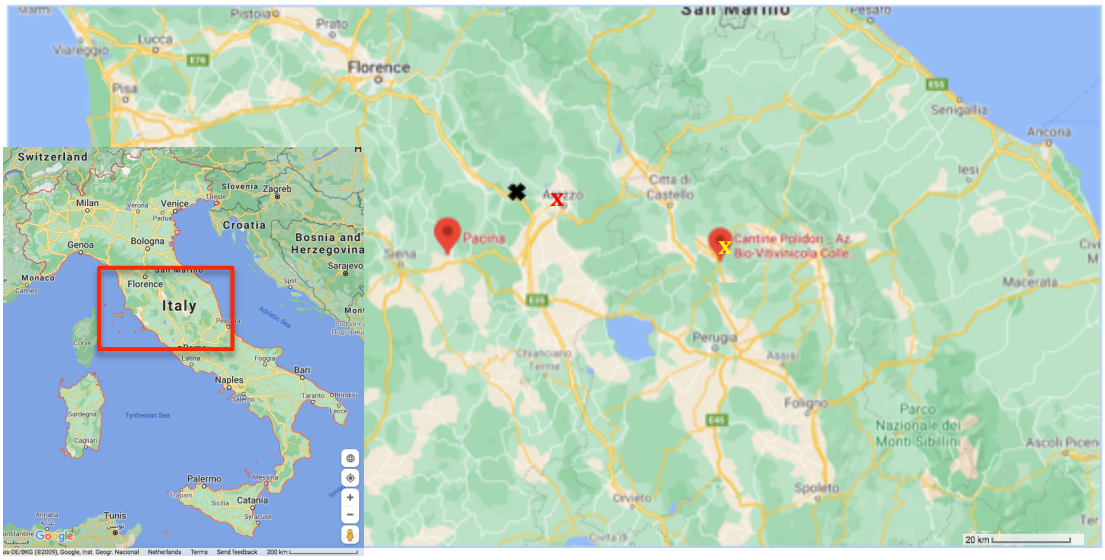

Fig. 4. Shows the locations of the two different wineries: Cantina Pacina and Cantina Polidori, while the black X shows the meteorological station used for Pacina, the yellow X indicates the meteorological station used for Polidori, while the red X indicates the meteorological station of Arezzo. The red square shows the area of the study that was zoomed in (Google Maps, 2020).

The following information on both Pacina and Polidori winery was provided during interviews with experts from each winery, during the research period from December 2020 to January 2021. The study area information has also been obtained from the conducted interviews. Interviewees were asked to provide background information of the specific winery, its history, land, and cultivation practices. The information from the interviewees will be referenced to as "*Pacina*" and "*Polidori*" in reference to their respective wineries through the rest of this study.

2.1.1 Pacina

Pacina winery is located in Tuscany, in Castelnuovo Berardenga, next to the city of Siena. The name derives from the Etruscan God of wine Pachna. The soils are oceanic ones, they are made up of tuff of Siena, which is a sedimentary rock, and a mix of clay and sand. It allows for water to penetrate deep into the soil due to the sand and high absorption due to the clay. There is barely any erosion due to the soil composition and the amount of plants "holding" the soil. The winery is found in a hilly open area that is exposed to sunlight all day and has no protection from the wind. There has been no evidence of vine disease due to the lack of humidity within the area.

Pacina's land is located approximately 10km south of the Chianti classic and next to Crete of Siena, in the Colli Senesi (*Pacina, 2020)*. Pacina used to be a convent in 900 A.D., and has been in the family for six generations. They have been

producing wine from 1967 and have not changed their cultivation practices since. They currently have 60ha of land, a polyculture, of which around 11ha of vineyards, and the remaining land is divided into forest, olive groves and agricultural land where they grow grains and legumes, which are chosen yearly. They have created a somewhat self-sufficient area, in the sense that they are able to sustain themselves in certain aspects of their daily lives, such as fresh produce (Pacina). Their wines are known for having strong, red fruity flavours and good acidity.

Their products are made with respect to the ecosystem, biodiversity, soil and local flora and fauna. They aim to be the least invasive as possible to ensure sustainability within their practice. The interviewee called their land "*virgin*", as they have never used chemicals and are part of the natural wine movement. They use no chemicals to tend the grapes as they have never found the need. Within the vinification process, natural yeast is added, but no sulphites are added. Old oaks, acacia and concrete barrels are used within the wine making process. When it comes to wine, they mainly produce red and only a few white wines. The company will provide data on alcohol percentage and pH, per year, per wine.

They do nearly everything by hand and use no machinery or technology when making the wine; moreover, the cellars have been left untouched for generations. La Malena wine has been made since 1996. Pacina Toscana is made from vines that are over 35 years old. They use the method of cloning, where they use their own cuttings and graft them in their other vines, to ensure that the plants are more prolific and better in terms of health and yield. For them, the long term health and sustainability of the area/ecosystem is something that they have at heart. There is slow natural fermentation and slow ageing that occurs within cement tanks and wood.

2.1.2 Polidori

Cantine Polidori is located in the region of Umbria, on a hill that ranges from 280-320m in altitude. It was founded in 1938 with only three hectares of vineyards. They had expanded to 33 hectares by 1984, however, due to their decision to convert to an organic winery, they had to decrease to a smaller plot of land of 24 hectares. They have not been using chemical fertilizers, pesticides, and insecticides for around 30 years. In 1979 they received the Controlled Designation of Origin (DOC) certification. Since the late 1990s, they have been utilizing traditional and ancient practices throughout the wine process. Due to this work, they have a certificate from the institute for ethical and environmental certification.

Polidori winery cultivates grapes with respect to nature and the local traditions. The soil that is found within the area is made of clay, which has a relatively large water holding capacity. The vines are cultivated on a slope therefore soil erosion is a threat. To mitigate these risks, they have therefore opted to have grass covered soil (instead of bare soil) to further aid in the retention of water and avoid surface runoff.

Their grapes are a mix of autochthonous and international varieties, each handpicked at the end of the maturation phase of the grape. Around 60% of their land produces black grapes, and the remainder is white grapes.

2.1.3. Wine Varieties Produced

Pacina and Polidori cultivate a variety of different grapes for wine making, some of which are endemic to the area. These grapes offer a diverse range of possible combinations to make the wines that they are known for, creating wines with their own taste and quality.

They have a smaller range of available grape varieties and thus a smaller range of wine produced (table 1). Both wineries share three grape types that are the same: Ciliegiolo, Sangiovese and Trebbiano Toscano - all autochthonous varieties.

Table 1. The table bellow illustrates the different grape varieties cultivated by the two different wineries, divided into red wines and white wines. The * demonstrate which grape varieties are found in the 3 different wine varieties used in this research from Pacina

			Polidori	**Pacina**
Wine Type	Red wines	Cabernet Franc	X	
		Ciliegiolo*	X	X
		Merlot*	X	
		Sangiovese*	X	X
		Syrah*	X	X
		Pinot Noir*	X	
	White wines	Chardonnay*	X	
		Greco	X	
		Incrocio Manzoni	X	
		Malvasia*	X	X
		Trebbiano Toscano*	X	X
		Verdello	X	

The grape varieties that are found within the wines produced by the wineries are *Canaiolo, Chardonnay, Ciliegiolo, Malvasia del Chianti, Merlot, Pinot Noir, Sangiovese, Syrah* and *Trebbiano Toscano*. Their characteristic and cultivation areas are described below, which were found from the national register of vines in Italy (Ministro delle Politiche Agricole, Alimentari e Forestali, 2020).

Canaiolo has decreased significantly in cultivated areas in Italy since the 1970s, going from around 8000ha to 1068ha in 2010. The grape is of medium size (12-24mm in traversal diameter), round shape, with a blue, sometimes purple, rather consistent skin thickness and very pruinose skin. The maturation of the grape occurs between the last ten days of September and the first ten days in October.

Chardonnay there has been an increase in cultivated surface area from 1982, to in 2010 there being about 20 000ha. Medium round sized grapes, thin to medium skin, average pruinoise skin, amber yellow colour.

Ciliegiolo has seen a steady decrease of cultivated land in Italy since 1982 from a peak of 6034ha to 1830ha in in 2010. The grapes are of medium-large size (12-20cm in diameter) round regular shape, with very pruinose skin, of a black purple colour, with medium thickness. The ripening occurs around mid to end August.

Malvasia del Chianti – Malvasia Bianca lunga has also seen a steady decrease in cultivated land from 1970 of 17 500 ha to 2200 ha in 2010. The grape is medium or small (11-13mm diameter) spherical, skin that is priuinose, and of a greenish light gold, and rather resistant skin, but less than the Trebbiano. The ripening occurs in the last part of September up to 15th of October.

Merlot has had a decrease from 1970, with just over 50 000 ha, to in 2010 there being about 28 000 ha. The berry is medium size, medium skin thickness, of blue-black colour. Ripening occurs at the end of September, beginning of October.

Pinot Noir like the Chardonnay has seen an increase in cultivation, In 1970 there was around 1500ha, and in 2010 5000ha. The berry is of medium size, slightly oval, with a thicker blue black skin. It ripens during mid September.

Sangiovese has seen an overall decrease in cultivated areas since 1982, where there were over 101 thousand hectares, and in 2010 it decreased to 71.5 thousand hectares in all of Italy (ministero.istat). The grape is of medium size (12-15mm), black-purple colour, similar to an ellipsoid, with a pruinose skin. Maturation occurs within the last week of September up to around mid-October. It is the main ingredient when making Chianti wine. Within Tuscany, the Sangiovese is the most cultivated grape variety, accounting for over 50% of grapes within Italy (Trombi et al., 2011).

Syrah in comparison to other grape varieties has seen an increase in cultivated hectares, from 52ha in 1982 to 6739 ha in 2010. The grape size is medium-small to medium (diameter of 10-12mm), oval shape, very pruinose skin, with a thin or medium skin. Ripening occurs in the last part of September.

Trebbiano Toscano is native to the region of Tuscany; its grape is usually of medium size (13mm-15mm), green colour, with a rather uniform round shape

with a pruinose/waxy skin. Maturation of the grape usually occurs within the first half of October.

2.2. Materials and Methods

To answer the three research questions, a mixed approach of quantitative and qualitative methods (Figure 5). The following steps will be used to determine the impact of climate change on wine: 1) analyse the relationship between temperature and historical analytical wine data, 2) use existing future climate projections to extrapolate possible wine characteristics under future scenarios, and 3) interview the wineries on how they have perceived current climate changes and possible future adaptation strategies.

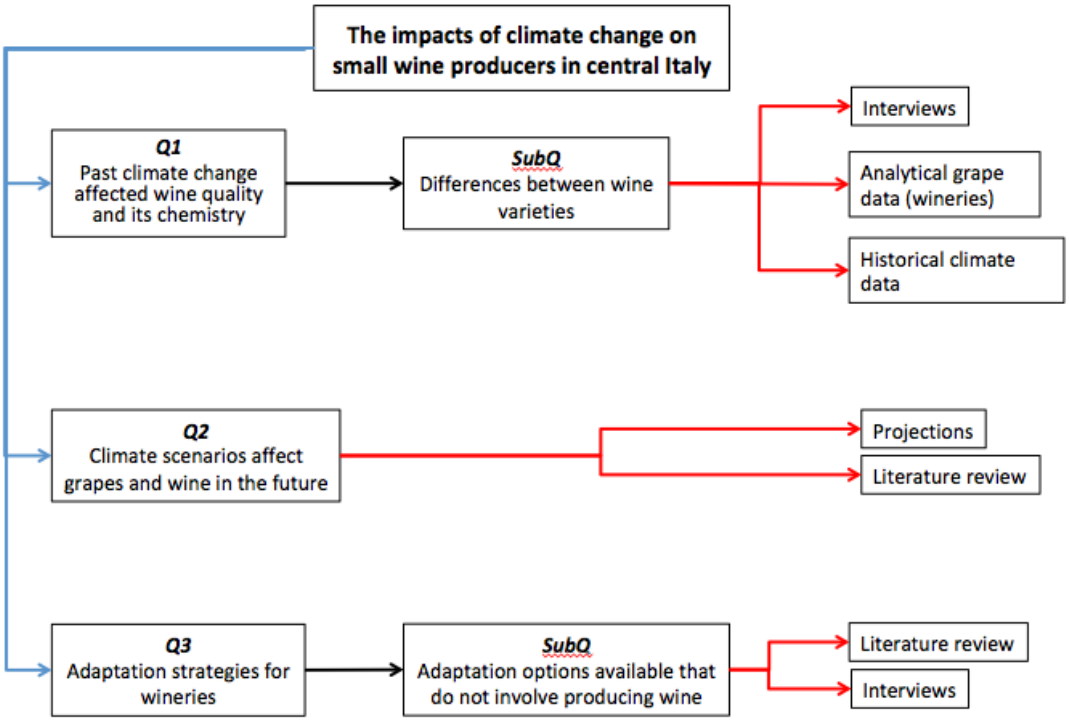

Fig. 5. Conceptual framework of research created by the author.

First, trends in wine chemistry will be analysed against trends in climate. Wine chemistry data are provided by the wineries, this will be as previously mentioned, pH, and alcohol level per wine per year. Only these variables were used as these were the only ones provided and that had a relatively good range of years.

Data for three different wines is gathered from Pacina winery, two red and one white. Pacina Chianti is a red wine made from a mix of Sangiovese grapes, Canaiolo grapes and Ciliegolo grapes. Over the years they have been blending the grapes, specifically in 2004 and 2010. The second wine is La Malena, also a red

wine, made from a mix of Syrah and Ciliegiolo grapes, again, over the years, blending occurred, going from a ratio of 75:25 in 2011 to 30:70 in 2017. The last one is La Cerretina, a white wine, a mix of Trebbiano Toscano and Malvasia del Chianti, a 50:50 ratio.

The data from Polidori winery on the other hand consisted of one red, one rosé and one white wine, from their Stemma Scuro range. The ratios of the wines remain unknown. The red wine consists of Sangiovese, Merlot and Ciliegiolo grapes. The rosé is made up of a mix of Sangiovese and Pinot Nero. While the white is combination of Trebbiano Toscano and Chardonnay.

Data for historical maximum temperatures was retrieved from the website of the region of Tuscany and Umbria (Regione Toscana, 2020; Regione Umbria, 2020). Maximum summer temperatures are important to observe specifically in the summer as this has an effect on the taste "balance" of the wine, overproduction of sugars and alcohol and how it affects the vintage. The "Average Summer Months" was calculated by taking the average daily maximum and minimum temperatures. Since the summer months are key in the composition of flavours within the grape, and the balance of sugars and acidity. The meteorological weather station in Umbria is located in Umbertide just a few kilometres from Polidori (Regione Umbria, 2020). Whereas the one in Tuscany is found in Marciano della Chiana, at 246m above sea level, and is around 35km from the Pacina winery.

For the statistical analysis, a linear regression analysis will be conducted using the program R-studio version 1.3.1093. This is to understand and test whether there is statistical significance on the effect of the average maximum summer temperatures (July-September) on both alcohol and pH for the different wines of the wineries. The correlation will be explored between pH, alcohol and the temperature. However, it is important to not that the pH data was not available from Polidori winery.

The second research question will be answered by using national projections from the Med- CORDEX model ensemble (ISPRA, 2015). Four different model simulation projections are used to determine the increase in summer temperature under two different RCP scenarios, 4.5 and 8.5, to then be able to use the previously calculated relationship to understand how the different scenarios could affect the different grape varieties. The Med-CORDEX models were derived from: ALADIN, GUF, CMCC and LMD and use average baselines from 1971-2000 (ISPRA, 2015). The models observe how the trend in local national temperature historically compares with the future projections of the two wineries. Consequently this can aid in estimating future temperatures and its possible effects on the two wineries and on their grapes.

The future projections of the two wineries were used by extrapolating data from 1971-2000 from the weather station in Arezzo. This specific weather station was used because there was no other available weather station that had this extended data for the areas surrounding the wineries. The calculation was done by taking a 30 year average of the maximum summer temperatures to utilize as a baseline for the projections. Then the temperature differences of the two mean RCP projections (RCP 4.5 RCP 8.5) and will be added to the baseline, to comprehend the estimated increases in temperatures and its effects.

The third research question was answered through interviews, a literature review, and findings from the first and second research questions. The semi-structured interviews were held in Italian, between December 2020 and January 2021, with open-ended questions to allow any additional information that is deemed important from the interviewee to come through. This will be done to better understand what has occurred throughout the past years within the vineyards and the differences that the wine makers have found with their wine making process and grape quality.

The structure of the interview allows for information that is layered and the questions allow for a basic skeleton. They will be semi-formal in Italian, recorded over Microsoft Teams, and last around one hour. Due to the Covid-19 global pandemic, I took the initiative to organise and conduct the interviews online, as it was impossible to conduct them face-to-face, allowing for a minimum of social interaction to be maintained. The questions can be found in Appendix I. The questions were divided in two main questions, in relation to the research question. The wineries were asked to explain their observations of the past and present of how climate change was affecting the winery, and alterations that they saw. Whereas the second range of questions was surrounding the future, on which type of adaptation strategies they would use, and what they would like to see from researchers. A consent form was signed by both wineries and are found in Appendix II.

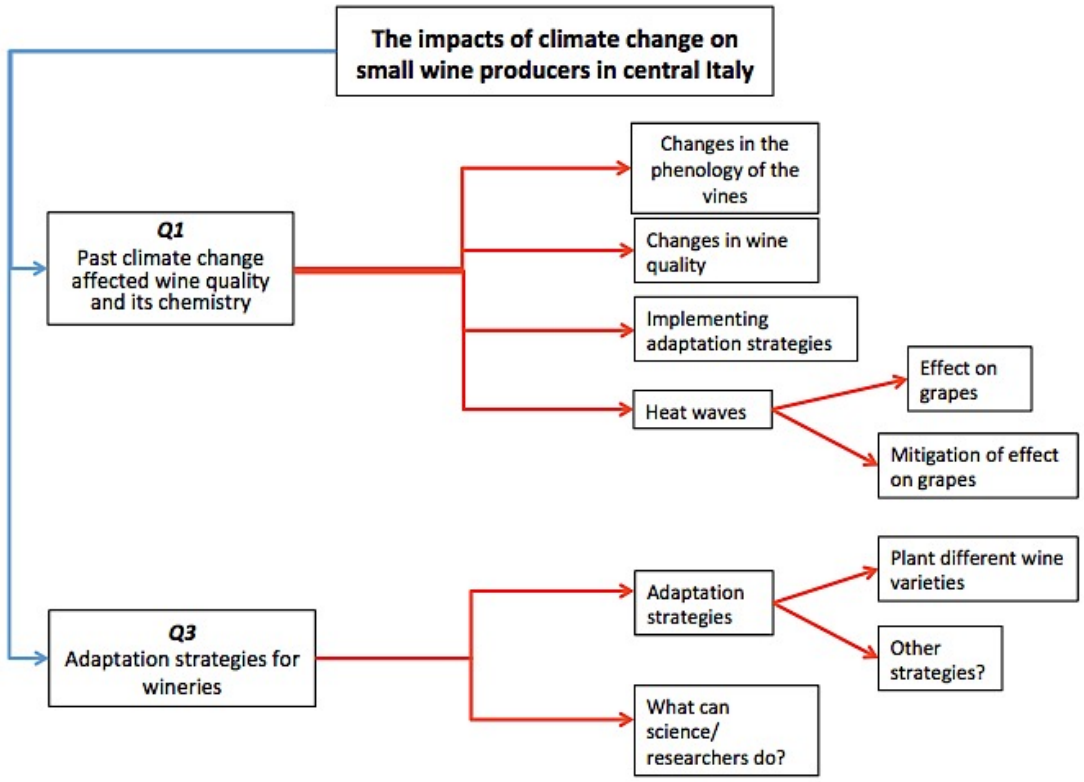

Fig. 6. Conceptual framework of interview questions created by the author to relate the research questions to one another.

3. Results

3.1. Effects of Temperature on Wine

When looking at the two weather stations (Figure 7), it is clear that both have exhibited annual variation in temperature over the years, meaning that there has been variation within the years and also an increase in temperatures. This is evident in the Tuscany weather station (Figure 7) where there is extreme variance in temperatures between the years. However, there are also similarities between the two locations. For example, 2003 shows substantial peaks in both areas. Furthermore, 2014 shows a very substantial decrease in temperature in both locations, this correlates to the intense rainfalls that occurred. In Umbertide (Figure 7), there is a drastic change of temperature within the 20 years time period, with a difference of about 5 degrees. The year that had the lowest temperature was 2014, with 27°C, whereas the highest temperature was in 2020, which was 33.4°C.

La Malena has the largest range of alcohol, ranging between 12.5% and 15.6%, and seems to be the least stable of the three (Figure 8). La Cerretina on the other hand seems to be a bit more stable, as the alcohol percentages ranges between 12.2% and 13.5%. On the other hand, the Polidori winery (Figure 9) revealed

that the wine that has the largest variance in alcohol percentage, in relation to temperature, is the red wine, ranging from 13.2% to 14.47%. In comparison, the rosé has the least amount of difference between the three wines. Pacina winery has a larger range of alcohol percentage, for both their red and white wines, in comparison to the wines that Polidori produces.

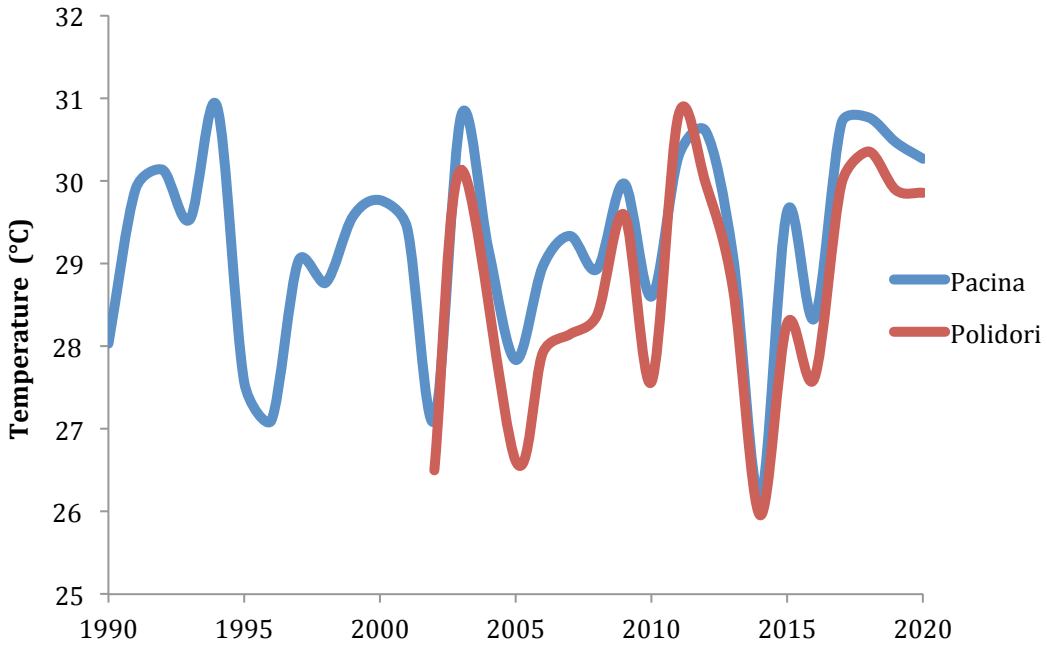

Fig. 7. Maximum temperature variations for Pacina and Polidori wineries, from 1990-2020.

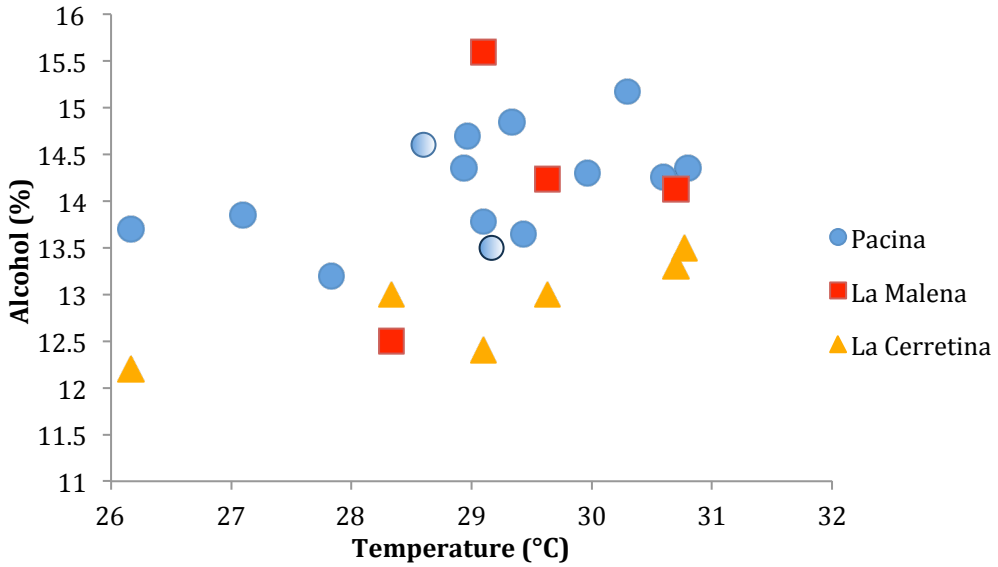

Fig. 8. Plotted data of the average alcohol (%) found in the wine, in relationship to the average summer (July-September) temperature in °C per year, found in the three different wines of Pacina winery. The two circles with the darker outline and gradient are years where the blending ratio changed.

For pH the wine that has the largest difference is also La Cerettina, ranging between 3.33pH and 3.78pH (figure 9), the one with the least difference is Pacina.

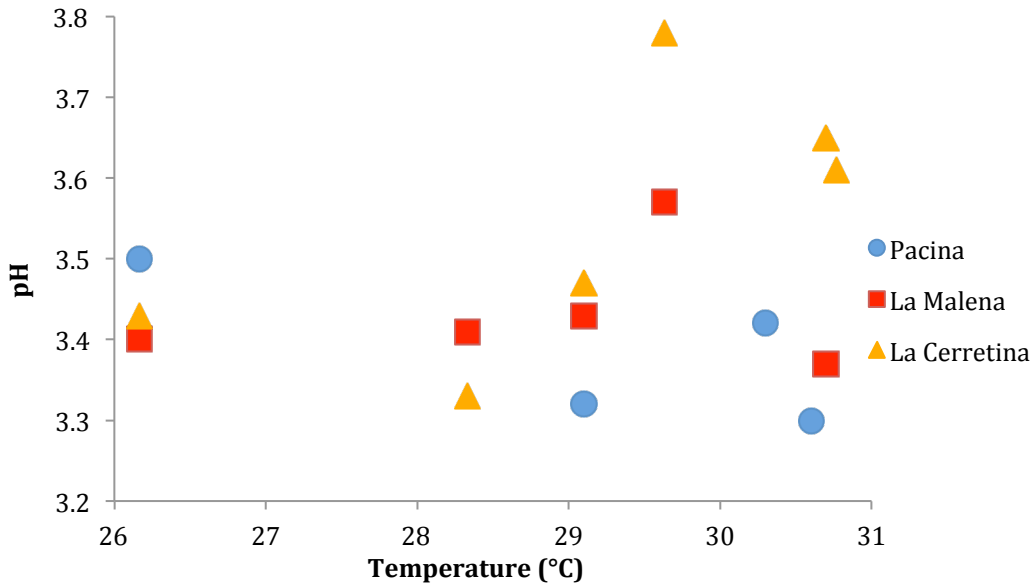

Fig. 9. Plotted data of the average pH found in the wine, in relationship to the average summer (July-September) temperature in °C per year, found in the three different wines of Pacina winery.

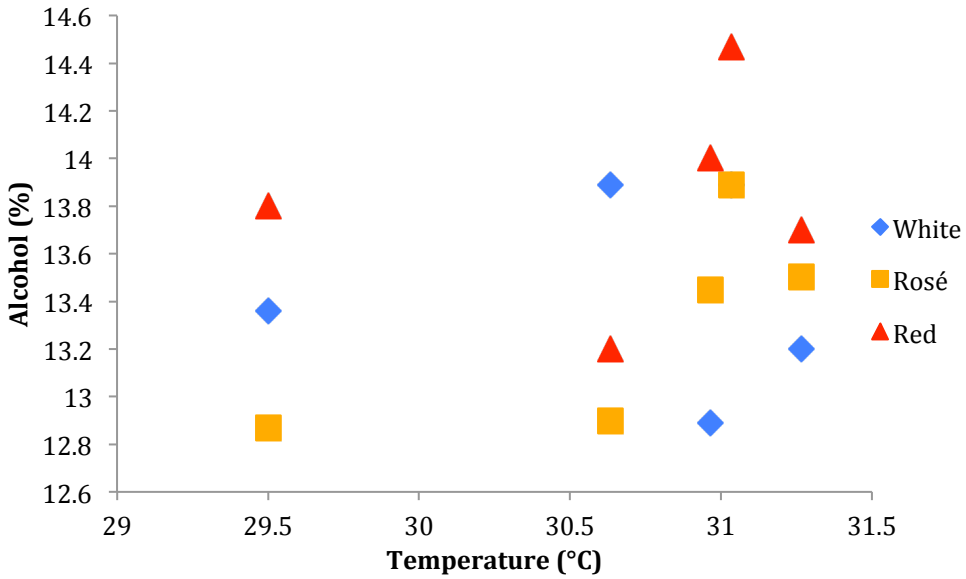

Fig. 10. Plotted data of the average pH found in the wine, in relationship to the average summer (July-September) temperature in °C per year, found in three different wines of Polidori winery, Umbria.

There has been no statistical significance in any of the correlation between temperature and alcohol, or temperature and pH's, due to the p values being larger than 0.05 (Table 2).

Table 2. ANOVA results of pH and alcohol, for the three different wines of Pacina winery**,** and the three wines of Polidori

Wine		Adjusted R^2	F statistic	p Value
Pacina	Alcohol	0.01843	1.244	0.2865
	pH	0.6765	7.274	0.1144
La Malena	Alcohol	0.4076	4.44	0.1028
	pH	-0.2864	0.1095	0.7626
La Cerretina	Alcohol	0.5155	6.321	0.06577
	pH	0.4308	4.783	0.09397
White	Alcohol	-0.3295	0.00875	0.9314
Rosé	Alcohol	0.3953	3.615	0.1534
Red	Alcohol	-0.2776	0.1309	0.7415

There are visible differences between RCP 4.5 and RCP 8.5 (Figure 11). From the national mean ensemble, the RCP 8.5 shows a possible increase of 7°C within 2090, whereas RCP 4.5, a possible increase of 4.5 °C at the end of the century. It is important to note that there are differences between the four different models. The LMDZ model has the largest variation in changes in temperature in both RCP 4.5 and RCP 8.5. Whereas the GUF model has the smallest change in temperature in both the projections, with in RCP 4.5 going from 1.6°C between 2021-2050, to 2.1°C at the end of the century. Within the RCP 8.5 on the other hand, it ranges from 2.6°C to 3.6°C, which is considerably less than the LMDZ model.

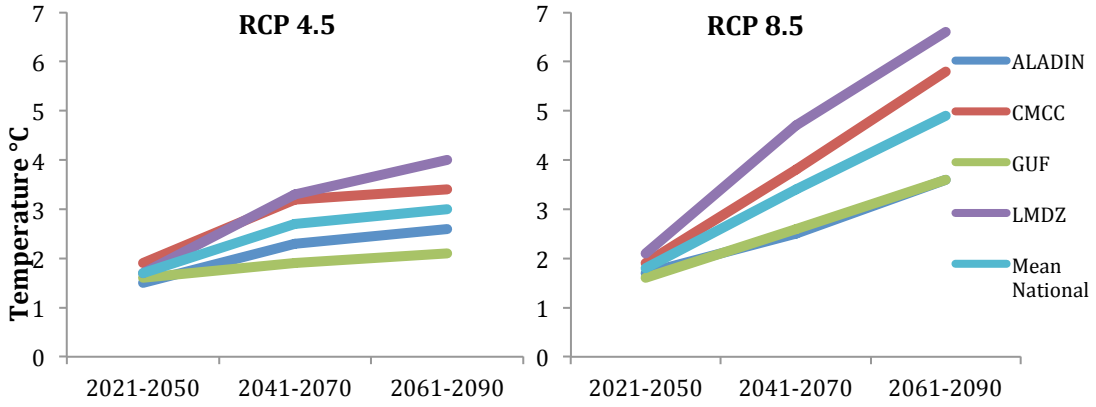

Fig. 11. Projections in Italy in relation to Med-CORDEX projections and mean national projections, within three temporal periods, at 30 year intervals

The potential mean maximum temperature at the end of the century under RCP 8.5 is of 35.15°C and 33.15°C under RCP 4.5, starting from a current baseline of 30.15°C (Figure 12). That is a 5°C and 3°C increase from the baseline period, respectively. The RCP 4.5 seems to plateau at the end of the century.

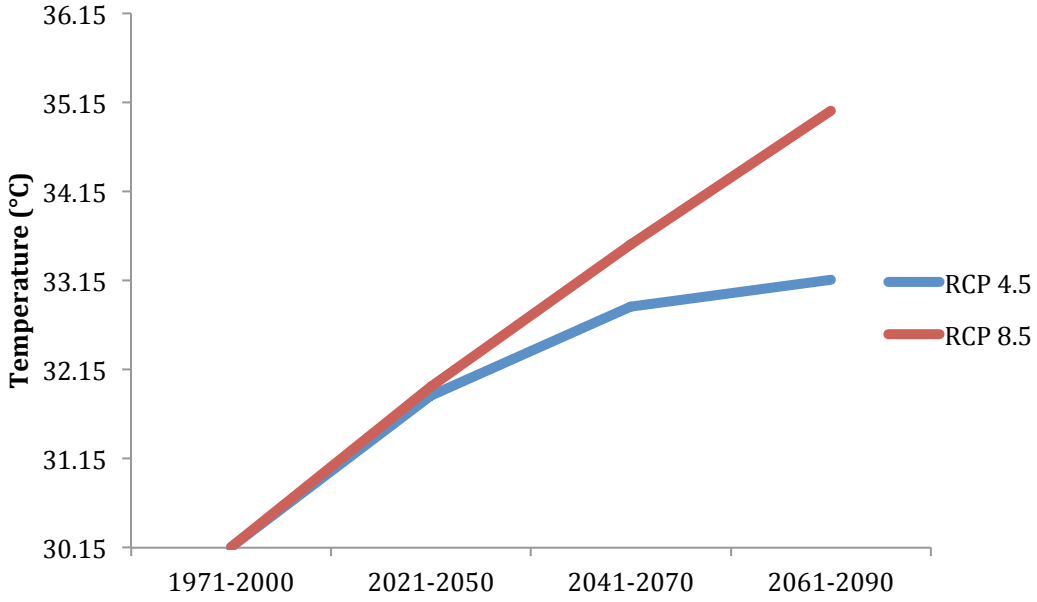

Fig. 12. Projections of Arezzo in relation to mean national Med-CORDEX RCP 4.5 and 8.5 projections, within four temporal periods, at 30 year intervals.

3.2 Interview Results

Through the recorded interviews, both Pacina and Polidori winery have noticed changes in quality of the grapes and wine, as well as phenological changes. These changes have been occurring within recent decades. The interviewees perceived this as the result of climate change. These observations were very similar when the phenological alterations and the quality of the grapes, alongside the wines. Their response and chosen adaptation strategies however have been slightly different, and the ones they intend to implement in the future are also diverse.

3.2.1 Phenological Changes

Pacina winery observed noticeable changes in the phenology of the wine. For example, they perceived changes in maturation of the grapes from 1980s-1990s. Maturation occurs earlier in the process, which is a clear trend in the last 5-10 years. Similarly, the harvesting period "from the 1980's has been anticipated by about two weeks" (Pacina). During heat waves, accompanied by periods of drought, there is withering of the grapes. The interviewees stated that they have seen less vigour in the plants, especially due to changes in precipitation and dry spells, leading to "a distribution of water within the soils, and the plants that is not equal, because it can rain for one month day after day, and then be dry for the next month". The interviewee mentioned that it is important to consider the age of the grapevine and how the climate affects the grapevine. "Older grapevines tend to react wisely to changes in climate" (Pacina). The term "wisely" is meant as that the vines become self-sufficient in regulating how they expend energy and therefore are able to produce grapes over the years, even when there are longer dry spells. Younger grapevines tend to expend more energy faster and generally encounter more discrepancies.

The Polidori winery has noticed that the maturation and harvest are onset by at least one month. In past years, maturation would occur between October and the beginning of November. Nowadays, the harvest is finished or finishing at the beginning of October (Polidori).

3.2.2. Changes in Wine

About 30 to 50 years ago, wines produced by the Pacina winery would have had a maximum alcohol percentage of around 13%. In the 1990s it was difficult to attain such a high percentage. Nowadays, all their wines contain "13-15% of alcohol, which has been a radical change" (Pacina). Even though there has been this significant change in alcohol percentage, the wines still hold a balanced composition. "The two main changes that we have noticed are an increase in alcohol and concentration of the wine" (Pacina). Due to the long ageing process

of their wines, Pacina is now opening and selling wines from 2014/2015. Even though 2014 was a particularly rainy year, the wines still have a rather high alcohol percentage (around 14%). However, these wines have a different concentration of flavours and can seem "diluted". The interviewee said "when there are heat waves, there is definitely withering of the grapes. However, this does not happen each year" (Pacina).

Cantine Polidori has noticed that the alcohol percentage and sugar levels of the wines have gone up overall. However, they have been able to maintain a good pH and overall complexity of the wine, without any intervention on their side. At the winery, 2003 and 2013 were two prominent years due to the warm days and long periods without precipitation. This led to withering of the grapes, particularly affecting the Pinot Noir and Merlot varieties. Polidori have also noticed that the Trebbiano Toscano has likely adapted best within the grape varieties, as it has larger grapes, and is an endemic variety.

3.2.3 Adaptation

Both wineries in the study intervene minimally with their grapevines. They conduct sustainable adaptation strategies, where they try to protect the plant and maintain a correct ecosystem and diversity of the area. This is a very important aspect of their cultivation.

Both wineries have implemented a spontaneous and permanent grassing/vegetation underneath the grapevines. This adaptation strategy allows for higher absorption and infiltration levels of water within the soil, and decreases the possibility for erosion. Furthermore, it prevents surface runoff when there are long periods of drought followed by sudden rainfall. Moreover, it permits for there to be a sort of microclimate to occur. The vegetation-covered soil allows less radiation absorption into the soil, which would have created a higher air temperature around the grapevine (Lerebouollet et al., 2013).

The grape varieties within Pacina that have been the most resilient towards climate change have been the three that are endemic to the area: Canaiolo, Ciliegiolo and Sangiovese. The Ciliegiolo has thinner skin but still managed to sustain itself well, although it is important to note that it needs to be harvested earlier on. The type of soil that is found within Pacina, and the fact that there is no bare soil, means that Pacina has not found the need to irrigate the vines.

As part of the third question of this research, the interviewees of both wineries were asked what they would like from researchers. Following recent years' discoveries, Pacina would like to understand how different plants respond to

each other and how planting some species aids the growth of others. In other words, how wine grapes and other species can coexist. They would like to know how to move away from monocultures of grapevines, and how to incorporate different species within the plot and therefore increase the biodiversity of the area. For Polidori winery, they would like to see more political changes. They are looking for solutions from politicians and the government.

As an adaptation strategy to climate change, Polidori winery has planned to diversify their business strategy from only selling wine. Between 1999-2006, new vines were planted, when the new owner took over. For the future, they are looking at olive products such as olive oil, since they planted an olive grove in the last 6 years and have a few secular olive trees. Therefore they are hoping to be able to produce olive oil as a new business strategy in the future.

4. Discussion

4.1. Effects of Past and Present Climate on Wine

Different studies have demonstrated that the increase in temperatures, due to climate change is usually more prominent during the summer periods (Di Lena, 2018). A number of studies conducted throughout Europe have also concluded that there has been an advancement in the phenological stages of grapevines of around 6 to 25 days (Di Lena, 2018). These findings are in line with the observations at the Pacina and Polidori wineries. The interviewees explained that they have noticed advancement of maturation and harvesting of at least 2 weeks, and sometimes up to a month. In the case of both Pacina and Polidori winery there was an increase in temperature during the summer. The data from Pacina does not show a statistically significant relationship between summer temperature, sugars, alcohol and pH. However, it was observed that as the temperature augments then the sugar concentration rises. This has a direct effect on the alcohol during the fermentation process, leading to higher alcohol percentages. In Polidori, the Pinot Noir and Merlot varieties may have reacted more severely, in that they withered, due to the fact that they have smaller grapes.

Multiple studies that focused on areas within Europe, especially in France, showed how climate change affects the phenology and composition of grapes. For example, there has been an earlier bud burst of 13 days and shorter ripening periods of around 8 days due to a 1°C increase in average temperature (Di Lena, 2018).

Different studies have demonstrated that higher temperatures have led to an increase of sugars within the grape, which has affected not only the final alcohol percentage but also the pH of the wine. A study conducted by Jones et al. (2010) demonstrated that more than half of the trends in alcohol increase globally, were due to climate (Teslic et al., 2016). The higher sugar concentration causes there to be more ethanol altering the complexity by increasing the bitterness of the wine (Teslic et al., 2016). Even though the results previously mentioned have shown to be inconclusive as they are not statistically important, there has been evidence from both Pacina and Polidori of the changes that are occurring. Polidori has noticed an increase in both sugars and consequently alcohol levels, however, the overall pH levels and "complexity of the wines have remained" (*Polidori).*

A reason for why the temperature did not have an effect on the data, both pH and alcohol, may be due to the fact that the grape varieties were blended. This was a surprising finding, also for La Cerretina, as it seemed as though there might have been statistical significance. The difference however with both Pacina and La Malena, in comparison to La Cerretina is that throughout the years, there was significant blending of the grapes, specifically for the latter.

Another reason for the inconclusiveness of the results can also be linked to the limited amount of data that was received from the wineries. The data range was small, in certain cases only 5 years. This made it difficult to have a proper insight on what occurred.

At the Polidori winery, no statistical significance was found for the relationship with temperature and alcohol in all three types of wine. This does not mean that there is no relationship but rather, due to the limited data set, it is difficult to assess the true nature. As the ratios were also unknown within the three types of wines, it could be that throughout the years they have been changing the ratios.

Grapevines, as mentioned above, have niche temperatures at which they produce optimal ratios of sugars and acidity to then be able to make wine. In Australia, for example, Ollat et al., (2016) showed that in the past there were more the ideal temperatures for the grapes to grow, compared to the temperatures occurring now. This is a trend that will continue to arise in areas that have been able to produce high quality wine from optimal climate conditions. Tuscany and Umbria, alongside other cultivation areas, have already been experiencing the negative effects of a changing climate.

A study conducted by Alston et al. (2011) demonstrated how, from 1980 to 2005 in California, there was an increase in Brix levels of around 0.20% per year. Therefore, the grapes had higher sugar concentrations and consequently the

wine developed higher alcohol percentages. Higher temperatures lead to more sugars, less acidity, and a decrease in the wine aromas, therefore decreasing concentrations of flavonoids and anthocyanin (Mosedale et al., 2016).

4.2. Future Climate

The magnitude of variation in future data to the historical data is quite impressive. This has already caused there to be an increase of 1-2% in alcohol within the wines of the two wineries, as described by both wineries during the interviews (*Pacina, Polidori)* Moreover, there has been a phonological advancement of 2 weeks up to over a month. Over the next decades, there will be a possible increase of an average of 3°C with the RCP 4.5 scenario, and 4.9°C with the RCP 8.5 projection within Italy. Extrapolating the effects on wine mentioned above with the 1°C increase, it is clear that a 3°C change will cause important changes to the wine sector within Tuscany and Umbria and to the rest of Italy.

With climate change progressing, this can mean that available land for grape cultivation will be altered. The study conducted by Bernetti et al. (2012) shows that the cultivable area of Tuscany in the future will decrease for vines. The suitability will be probably only be 40% of cultivable area, to a mean of around 22% of the area. Similarly, Hannah et al. (2013) projected that in 2050 areas such as Tuscany in Italy or Bordeaux in France will see a noticeable change in land that will be appropriate for grapes. The decrease in suitable land can be attributed in part to the increase of temperatures. This is something that wineries need to consider in the future, and be able to adapt to them.

In the future, high temperatures can cause an array of different effects on the grapes. For example, temperatures above 30-35°C, can cause damage to the leaves and grapes by burning them, thereby damaging their quality (Spano et al., 2008). Higher temperatures will consequently mean that there will be more sugar found within the grape and therefore the alcohol levels will increase in the wine. The wine will also lose its complexity (Ollat et al 2016). The concentration of malic acid goes through degradation as a consequence of higher temperatures (Ollat et al., 2016).

Higher temperatures have negative implications when it comes to pests. With an increase in temperature, the European grapevine moth (*Lobesia botrana*) may expand its habitat range (Mosedale et al., 2016). The grapevine moth has been of particular concern to Tuscany as it is already a threatening species that can cause further damage and consequences alongside climate change. It is of high importance to understand not only how the plants will be directly affected by the change in climate, but also how it will be affected indirectly.

There will inevitably be “tipping points” that will be reached, meaning that adaptation strategies will be exponentially less effective and arrive at a threshold. Climate change will create a magnitude of variation that the strategies set in place will not be able to mitigate (Werners et al., 2015). This is something that is related to wineries and wine-making due to the niche at which grapes maintain their perfect balanced ratio.

4.3. Adaptation Strategies

The future prospects of how climate change will affect the world and how it will consequently alter the climate for wineries is highly dependent on our future actions, alongside those of larger players. This will of course not only have an effect on wineries and agriculture but on many other aspects of our daily lives.

It is also important to understand that there are effectively a multitude of adaptation strategies, not only in the wine and agricultural sector, but also in other areas that can aid in the future of an ever-changing climate. When talking about the future for both Pacina and Polidori, it tended to be more as an abstract concept. There are still many unknowns to what will happen and exactly what decisions they want to take. This may also be due to the fact that they are both yet not very negatively impacted by the effects of the climate.

However, it is critical to comprehend the boundaries of different stakeholders, and the risks and change that they are ready to take (Werners et al., 2015). In the case of Pacina and Polidori, they require nature-based solutions as this is their current business model, and it is at the core of their essence.

There are numerous adaptation strategies that can be used for the two wineries in this study, however, both found it of high importance that these strategies remain as low intervention strategies as possible. As climate change is a multifaceted problem, there need to be a range of strategies to tackle it (Ollat et al., 2016).

Both wineries have low intervention schemes and no machinery so specific engineering strategies in the near future will not be a possibility for them. They need nature-based solutions, and low-intervention strategies, to ensure that the ecosystem and environment is not disturbed. This is something that Pacina has already been doing by for example cutting some of the leaves off to ensure that the grapes build a thicker skin.

Poni et al. (2009) conducted a study for a possible minimally invasive adaptation strategy for red grapevines and ripening. They looked at two grapevine varieties,

Lambrusco and Barbera, and found that defoliating the vine before blooming led to an increase in skin, seed and berry mass. Another study conducted with Sangiovese also showed the same results. If the grapevine is defoliated closer to blooming it means that there will then be a better composition of grapes. A possibility would be that of rearranging the canopy of the vines to decrease the sun exposure of the grapes. This is already something that Pacina winery does, and could also be adopted by Polidori winery. Or decrease the grapes' exposure to the sunlight, meaning that there is a colder microclimate. This ensures that there is then the correct build-up of sugars, which is slowed down, and the suitable acidity (Bernardo et al., 2018).

In the study conducted by Nicholas et al (2012), there was an in-depth research on different adaptation strategies in Northern California, USA. They demonstrated adaptation strategies on different levels, not only in the sense of winemaking, farming and social decisions, but also on a more biological, chemical and physical level. Ranging from irrigation, to blending grape varieties, and adding shade cloths so that the grapes and leaves do not receive sun damage

Blending different grape varieties within the wine creates a more stable alcohol and pH variable, for example in the Pacina wine. This concurs with the different literature, where they have used blending of grape varieties for variability within the years and as an adaptation strategy for the future (Lereboullet et al., 2013).

Another method that could be used by both of the wineries, while still maintaining their low intervention practices, is that of pruning (the trimming or cutting of branches of plants) (Lereboullet et al., 2013). Pruning is a traditional practice found in Italy (Poni et al., 2016). It is done yearly during the dormant period of the plant, for example to redirect the plant by cutting it at the bud, the arrangement of the grape, or remove dead or damaged branches (Poni et al., 2016). Pruning can affect the phenology of the grape in postponing the bud break of the vine. This would result in maturation and harvesting with a more fruitful ratio of sugar and acids within the grape. While at the same time improving the microclimate of the grapevine (Poni et al., 2016). A study conducted by Zheng et al., (2016) demonstrated that minimal pruning can be used as an effective way to delay grape maturity.

A possible adaptation strategy for Pacina and Polidori could be planting different autochthonous varieties, specifically those that are lesser known. This would increase the diversity of the grape varieties and further allow for the cultural connotation to increase. They may also find varieties that are better suited for the different climate (D'Agata, 2014). This could be done by grafting (the art of transplanting a living plant onto an already established one) a different variety onto the existing one, which would diminish establishment time of the new

variety, rather than completely replanting it (Nicholas et al., 2012). Grafting is something that Pacina winery already does, but with clones of their grapevines, hence why it would be considered as a nature-based solution. An addition to this strategy can be using clones that have certain characteristics. This is because within the viticulture sector, certain clones were favoured for elevated yield and for certain sugar accumulation (van Leeuwen et al., 2019)

There are certain adaptation strategies that are higher intervention practices, outside of the scope of the nature-based solution that requires no to minimal intervention. If the climate changes or effects become too detrimental to the wineries, there may come a time when the wineries will need to use different strategies that go beyond the nature-based solutions. This may be for example using irrigation schemes for when there are long periods of dry spells and heat waves. Polidori has noticed an advancement of the maturation period of a month in the past 30 years, meaning that adaptation strategies need to take place. As seen throughout the former years, there is an increase in not only temperatures but also drought, all year round. It is of importance to note that the decrease of precipitation throughout the winter that has been noted in certain areas means that the water reserves within the soil are not replenished (Ollat et al., 2016). This is something that has been noted by the Polidori winery. The recent summer droughts and increase in summer temperatures have meant that they have had to use "emergency" irrigation. This is something that was further noticed by Pacina winery, where the plants had less vigour when there was a decrease in precipitation. Irrigation in their cultivation is something that both wineries may need to consider in the future as a more permanent solution.

Having a diverse business strategy is important when it comes to adaptation strategies. This is not only true when it comes to different grape varieties but also variety in produce and business models. This is because it takes time for possible new grapevine varieties to grow. Wine tourism has become a growing industry, especially within the last 25 years, and could be seen as a possible plan. It could also help to grow awareness of the challenges that the wine industry is facing (Festa et al., 2020; Messina et al., 2019).

There are adaptation strategies not specific to wine, that can be implemented at national level through government action, which is what Polidori winery would like to see happen. To revise the DOC or AOC (Appelaton d'Origine Côntrollée) could be implemented by the EU not just in Italy but across the whole of Europe. It would mean categorizing different grape varieties and locations as DOC. This is because, in the next coming decades, it may no longer be possible to cultivate the current DOC grapes in their specific areas (Metzger, 2011).

This study has found that there needs to be a contribution from academia when it comes to mitigating and adaptation strategies. It is important to understand how wineries can fight and tackle this growing problem. This can be achieved through a transdisciplinary and multidisciplinary approach. Adaptation strategies can be created at different levels, site, planting, farming and wine making. It is important to understand the level of adaptation needed for the wineries to continue or to improve their functioning of the system. While at the same time taking into consideration the thresholds and limits at which they want to work. It is key to understand the importance of quantifying the different vulnerabilities that viticulture's and farming structures have, in order to create adaptation strategies that ultimately aid in building resilience against climate change (Bernetti et al., 2006).

4.4. Limitations and Recommendations

There were limitations that arose during this study. The most important was the response rate and collaboration of wineries in general. This was low on behalf of wineries in general, and not specifically those that aided in the making of this study. In the original plan of the research, there was participatory research alongside fieldwork. However, due to the Covid-19 pandemic, there was a low response rate of the wineries, both via email and on the telephone, which is an important limitation to take into account. This would have been mitigated by going to the winery and conducting interviews face to face (which was impossible due to the COVID-19 pandemic). Moreover, the availability of data, both when it came from wineries and from governmental agencies for meteorological data, was limited and inconsistent. Previous studies have demonstrated and confirmed the challenges that arise in trying to engage with small- and medium-sized business owners in research (Alonso & Bressan, 2014).

A recommendation to the wineries is to maintain, track and store data to then be able to look back at how the different years/vintages have seen differences. There is not a lot of wine data available; this has to do with the fact that they have only recently begun to save data. This relates to how the European Union (EU) is working towards more digitisation within the agricultural sector. This would led to an increase in transparency between the farmers and the consumers, and more trust between them (European Commission, 2021)

It is important to note that there are inconsistencies within the data, such as incomplete or not robust and large enough data sets. However, there is some validity in exploring these trends within the data to try to comprehend what has happened and what can happen in the future, while ultimately understanding how to adapt.

Covid-19 has created novel challenged by not being able to conduct a proper participatory research or ensure active engagement by the wineries. There would have most likely been a higher response rate had there not been the pandemic. Participatory research is "knowledge for action", this strays away from conventional research in the sense that it does not only give recommendations, but is a more bottom-up approach (Bergold and Thomas, 2012; Cornwall and Jewkes, 1995). Perspectives are taken locally, working alongside the people that are within the research, to find real solutions to their problems, while engaging with their perspectives. This is highly important in the viticulture sector because different wineries have diverse approaches when it comes to the vinification process, and it is important to acknowledge them and work with them to make sure that the chosen adaptation strategy can be implemented.

Interdisciplinarity is of high importance when looking to move forward with research, specifically when it comes to climate change and wineries (Bonfante et al., 2017; Ollat et al., 2016). This is because adaptation does not stem only from an environmental perspective but also from a social and economic one (Mosedale et al., 2016). It is not only wine and the plant itself that will be impacted, but the communities and economies on a more local level too. There needs to be participatory research with different stakeholders to truly try to solve and react to the upcoming issues, and ensure a sustainable future, while looking for not only short-term but also long-term solutions.

Further in-depth research needs to be conducted to determine the changes that will occur on a small scale by looking at different models of how the climate will be affected. For example, conducting a spatial analysis and creating a suitability map to see what will specifically occur in that area, may help in understanding what types of grape varieties to plant. This would ensure a more accurate analysis and outcome. Another aspect that can be added is that of using the RCP projections of 2.6 and 6.0, leading to a more realistic scenario for the future, as there are researchers that note that the RCP 8.5 scenario is too much of an extreme, and the likelihood of it happening is questionable (Ho et al., 2019; Ritchie and Dowlatabaldi, 2017). One reason for this is that the estimated coal reserves are actually lower than what was thought there to be, and hence the emission from that sector will not be as high as imagined (Ritchie and Dowlatabaldi, 2017)

Furthermore, an important factor is working more closely with the wineries and be able to conduct participatory research. This is to better comprehend how each winery is singularly being affected, what their current practices are and what can

be done in the future to mitigate and adapt to climate change to minimize the amount of losses.

5. Conclusion

To conclude, changes within the wine sector have been already occurring over the past decades as a result of climate change, this has been confirmed not only by academic literature, but also by the interviews conducted with the two wineries. Climate change in recent years has changed the percentages of alcohol of the different wines in both wineries, by an increase of 1-2% while at the same time maintaining the complexity of the wine.

The climate scenarios demonstrated that there would be higher summer temperatures in the two regions, under all of the projections. This means that the sugar levels in the grapes will continue to increase, creating higher alcohol percentages, and move towards having non-optimal acidity levels. This could lead, in the near future, to imbalanced wines, even though this is not necessarily what the wineries have noted in the last few decades.

The adaptation strategies that both wineries can implement are nature-based solutions that require low to no intervention. This can range from blending grape varieties to produce wine to cutting the canopy and redirecting it at certain stages of the vines cycle, ensuring higher temperature resilience. There will possibly come a time when the wineries will have to adopt strategies that stray away from nature based solutions and their ethos, such as emergency irrigation. Adaptation strategies that do not involve producing wine are, for example, diversifying the winery business by selling a diverse range of non-wine products.

There are definitely trends and relationships between climate change and wines. Higher temperatures have been decreasing the complexity of the wine while increasing alcohol percentages and pH levels. It is important to comprehend the climate changes that will occur as this directly impacts the quality and quantity of wine produced. A key finding is that extreme temperatures cause not only phonological changes but also cause an increase in sugar levels, leading to wines with much higher alcohol percentages than before. These alterations will undoubtedly continue to happen, which is why finding adaptation strategies and solutions is vital to not only the wineries but also for the continuation of the culture and history surrounding wine in Italy, and all over the world.

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Appendix I

Questions:

Can you tell me about your winery?

Have you noticed changes in the phenology of the vines?

- and temperature
- Heat waves - have they had effect on the grapes?
  what was done to avoid the heat affecting the grapes?
- Blending grape varieties? (specifically to Pacina)

Have you been implementing adaptation strategies?
If so, which ones?
Would you consider implementing others?
Would you consider changing crop varieties? At intervals?
Or cultivate the vines in different areas? Higher up in latitude?
Would you think in the near future of planting different varieties?
Or of blending different grape varieties?

Appendix II

Utrecht University **INFORMED CONSENT FORM for participation in:**

Climate Change Impacts and Adaptations for Small Wine Producers in Central Italy

To be completed by the participant:

I confirm that:

- I am satisfied with the received information about the research;
- I have been given opportunity to ask questions about the research and that any questions that have been risen have been answered satisfactorily;
- I had the opportunity to think carefully about participating in the study;
- I will give an honest answer to the questions asked.

I agree that:

- the data to be collected will be obtained and stored for scientific purposes;
- the collected, completely anonymous, research data can be shared and re-used by scientists to answer other research questions;
- video and/or audio recordings may also be used for scientific purposes.

I understand that:

- I have the right to withdraw my consent to use the data;
- I have the right to see the research report afterwards.

Name of participant: [redacted] P

Signature: [redacted] Date, place: 17/12/20, Umbertide PG

Utrecht University **INFORMED CONSENT FORM for participation in:**

Climate Change Impacts and Adaptations for Small Wine Producers in Central Italy

To be completed by the participant:

I confirm that:

- I am satisfied with the received information about the research;
- I have been given opportunity to ask questions about the research and that any questions that have been risen have been answered satisfactorily;
- I had the opportunity to think carefully about participating in the study;
- I will give an honest answer to the questions asked.

I agree that:

- the data to be collected will be obtained and stored for scientific purposes;
- the collected, completely anonymous, research data can be shared and re-used by scientists to answer other research questions;
- video and/or audio recordings may also be used for scientific purposes.

I understand that:

- I have the right to withdraw my consent to use the data;
- I have the right to see the research report afterwards.

Name of participant: [redacted] B

Signature: [redacted] Date, place: 9/03/2021 Perugia