Ripe for Disruption

Climate Change and the Future of the Wine Industry

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Abstract

Winemakers are some of the most seasoned climate scientists in the world. Agricultural techniques required for harvesting grapes accumulated over decades (sometimes centuries), coupled with precise knowledge of environmental patterns surrounding their vineyards, provide winemakers with unrivaled expertise and techniques to optimize wine production. Because climate is the most essential ingredient required for wine production, it affects the level of suitability of grape varieties to a particular terrain, and determines the type and quality of the wine that can be produced. However, recent extreme weather events also confirm that grapes are extremely sensitive to sudden changes in temperature and other unforeseen fluctuations. These shifts raise difficult questions for the wine industry and could potentially disrupt centuries of cultural practices and agricultural norms in winemaking while also unlocking new opportunities in adapting to climate change, something that will require innovation and flexibility.

While the topic of climate change in the wine industry attracts much media and academic attention and generates important discussions within the wine industry, most of the existing empirical evidence is either geographically localized, confined to a specific grape variety, and/or difficult to grasp for wine enthusiasts. In addition, it is also difficult for a wine aficionado to access updated and/or user-friendly applications of cutting-edge climate change information suited for the wine industry. To provide a glimpse into the future of the wine industry, the Ripe for Disruption project uses geovisualization tools to help the reader better grasp which wine regions (and wineries) are more likely to be on the frontlines of global warming in the future. This will be complemented by a closer look at two recent “freak” weather events that impacted the “Old World” and the “New World”, before finally, exploring the different opportunities and adaptive changes the wine industry might go through as a result.

Introduction

Climate is, undeniably, the most powerful ingredient required for the winemaking process. Historical archives and, more worryingly, a growing number of extreme weather events have also shown how climate can become its strongest source of disruption.[1] Centuries of practice have demonstrated this complex relationship - first in the “Old World” (France, Italy, Spain, etc.), and more recently in the “New World" (California, Australia, South Africa, Argentina, etc.). In both worlds, cultural traditions often coupled with recent agro-technological advances in viticulture demonstrated the importance of combining the *terroir* (or its geology), with landscape and topographical considerations, distinct soil quality, and most importantly, the climate (often defined as ideal temperature flows and reliable rainfall patterns).[2] This tight but fragile blend of parameters has been helping winemakers over many decades (or centuries in some cases) in determining which grape varieties are the most suited to a given environment and providing important indications on upcoming harvests (such as the size or quality of a given yield).

Increasingly, many wine industry observers explain that a single extreme weather event such as frost, drought, or wildfires can, all of a sudden, put an entire year’s worth of harvest at risk by damaging vineyards, whilst instilling a growing sense of uncertainty in the long term. For example, in France, winemakers have recently faced unanticipated, late frosts, and hails in the spring of 2017 and 2021, while in California, Australia, and in South Africa, winemakers have had to contend with ravaging wildfires (and smoky, toxic after-effects) as well as intricate drought and recurring water shortages episodes. While these meteorological threats are not new given that wine producers have developed ancestral methods and/or innovative techniques to anticipate, minimize, or swiftly recover from their occasional effects for many decades or centuries, their growing frequencies coupled with fluctuating intensities and unforeseen, abrupt changes in climatic conditions is what gradually worries the wine industry.[3] To make things worse, wine producers are simultaneously bracing for a more significant but much more subtle existential threat putting at risk thousands of vineyards around the world: global warming.

While the topic of climate change impact in the wine industry has attracted much media and academic attention, and is increasingly informing many conversations among climate scientists as well within the wine industry itself, most of the empirical evidence demonstrating the impact of climate change on the wine industry remains geographically very localized and/or confined to a specific grape variety. In addition, while the recent the Intergovernmental Panel on Climate Change (IPCC) reports have provided a plethora of technical datasets and cutting-edge

[1] (Daniels, 2021)
[2] (Encyclopedia, 2018)
[3] (McAllister, 2021)

scientific evidence on climate change[4], it can be challenging for a wine *aficionado* to find an updated and accessible application of this cutting-edge climate change expertise adapted to the wine industry. This project seeks to shed light on these two knowledge gaps and help the reader to have a nuanced understanding of the growing impact of climate change on the wine industry. This will be implemented by (1) compiling a macro-level overview that explains how global warming has been affecting the wine industry in recent years, (2) mapping out at a global level which wine-producing regions around the world are more likely to be "hotspots" than others due to global warming in the coming decades; and (3), showcase the different local challenges and adaptive changes the wine industry might go through as a result.

Treatment

Chapter 1: The Expansion of the Wine Industry Overtime

"Wine is one of the most complex of all beverages: the fruit of a soil, climate, and vintage, digested by a fungus through a process guided by the culture, vision, and skill of an individual man or woman." (Neel Burton)[5]

Typically made from fermented grape juice, wine is one of the most popular alcoholic beverages consumed in the world today. This beverage has been produced for thousands of years and enjoyed by different civilizations, with some of the earliest evidence of wine drinking tradition found in China (c. 7000 BC), but also in Georgia (6000 BC), Persia (5000 BC), and Italy (4000 BC). Whether it's the Greek cult of Dionysus, the Romans with their Bacchanalia celebration or the Christians and the Eucharist, wine also played an essential role in religious traditions over time. Wine production and consumption increased, burgeoning from the 15th century onwards as part of European expansion. The "New World" wine still has some connection to Spanish traditions - for example, viticulture in the Southwestern United States started within New Spain because Catholic friars and monks first produced wines in New Mexico and California. Today, given their heritages in connection to sacramental wine, the largest wine regions in Italy, France and Spain are still deeply connected to these ancient roots.[6]

Despite the devastating 1887 phylloxera louse infestation, advances in modern science and technology have since accompanied the wine industry to bring its production to an industrial scale.[7] As a result, wine consumption is now widespread throughout the world. As viticulture techniques evolved through the centuries, Spain, Italy and France also happen to become the

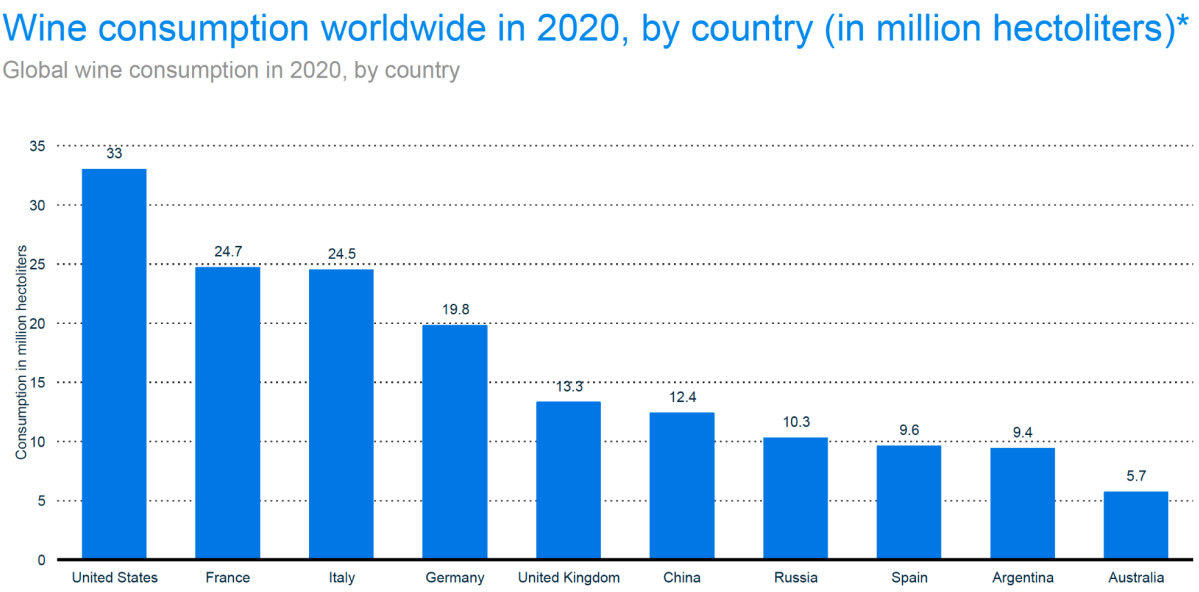
[4] For more information: https://www.ipcc.ch/
[5] (Burton & Flewellen, 2014, p 52)
[6] (Encyclopedia, 2018)
[7] (Tattersall et al., 2015)

most prolific wine-producing countries in the world.[8] To this day, these same three countries are still the leading wine-producing and wine-exporting countries (based on volume).[9]

Global Wine Consumption and Post-COVID Revenue Forecast

To better understand the societal importance, commercial evolution, and industrial scale of the wine sector, it is important to look at how much wine is currently being consumed at a global level, and consider ongoing production trends and potential impact of the recent COVID-19 pandemic at a global level. In other words, where are the largest concentrations of wine consumers and can a global shock such as the ongoing COVID-19 pandemic potentially disrupt these existing production and consumption patterns?

At a national level, according to OIV estimates, the largest wine markets (aggregate volume) are the USA, followed by France and Italy.[10] Approximately half of all the wine produced in the world is consumed on the European continent (48%) - see below.



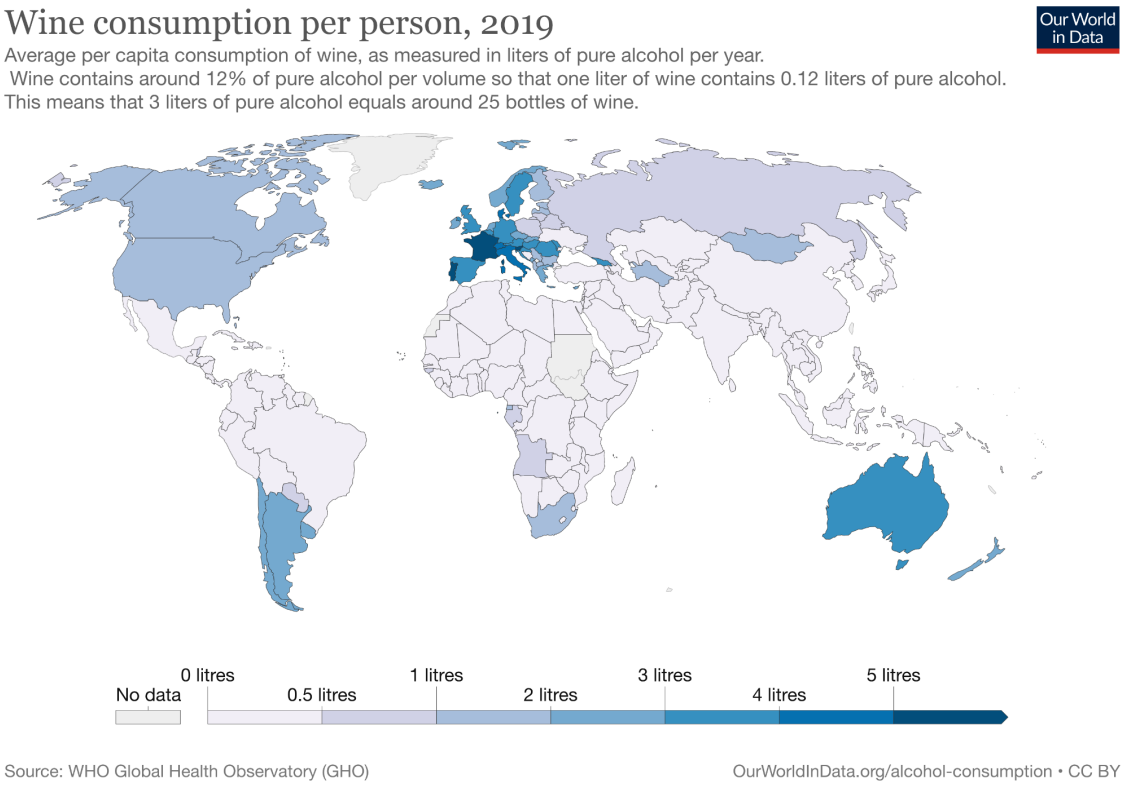
Source of graphic: Shaulova & Biagi, 2021
Dataset: OIV, 2020

[8] Most of the wine data (global level) provided in this chapter comes from the OIV (International Organization of Vine and Wine), unless otherwise noted. For more information: https://www.oiv.int/

[9] As seen in the following subsection, other important wine-producing regions in the world include the United States, Australia, South Africa, Germany, Argentina, Chile and China.

[10] The USA accounted for 14 percent of the world's total wine consumption in 2020, ranking as the first country in the list that year. Following with 11 percent was France, whose population amounts to only around 20 percent of the United States'.

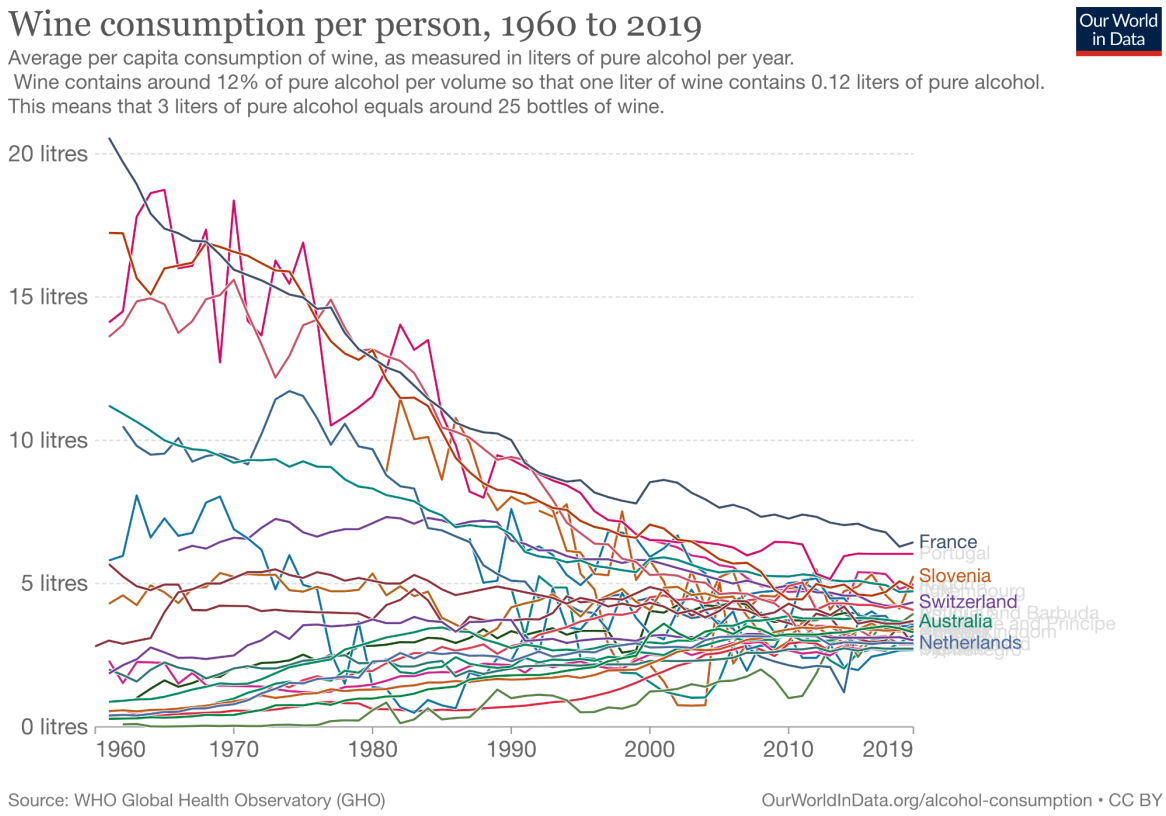
From a public health perspective, at an individual level, the map below displays global patterns of wine consumption, but focusing this time on the estimated average wine consumption per person older than 15 per year. This is an indicator based on the World Health Organization (WHO) calculations and is measured in terms of pure alcohol/ethanol intake (excluding beer and spirits) per year per person, rather than the exact quantity of the wine beverage itself.



Source of graphic: Our World in Data
Dataset: WHO, Global Health Observatory (GHO)

The global average wine consumption was 0.95 liters of pure alcohol per person in the latest available year (2019), which is equivalent to 7.9 bottles of wine per person on a yearly basis.[11] As the map shows, the average per person wine consumption varies widely across the world. We see large geographical differences: wine consumption across North Africa, South Asia, and the Middle East is particularly low — in many countries, close to zero. At the upper end of the scale, wine intake across Western Europe is highest, ranging from 3.5 to 6.5 liters of pure alcohol per person per year in countries like France, Slovenia, Portugal, Italy, Switzerland or Slovenia. This is equivalent to a range of 35 to 55 bottles of wine per person per year (equivalent to a half bottle to one bottle of wine per person per week).

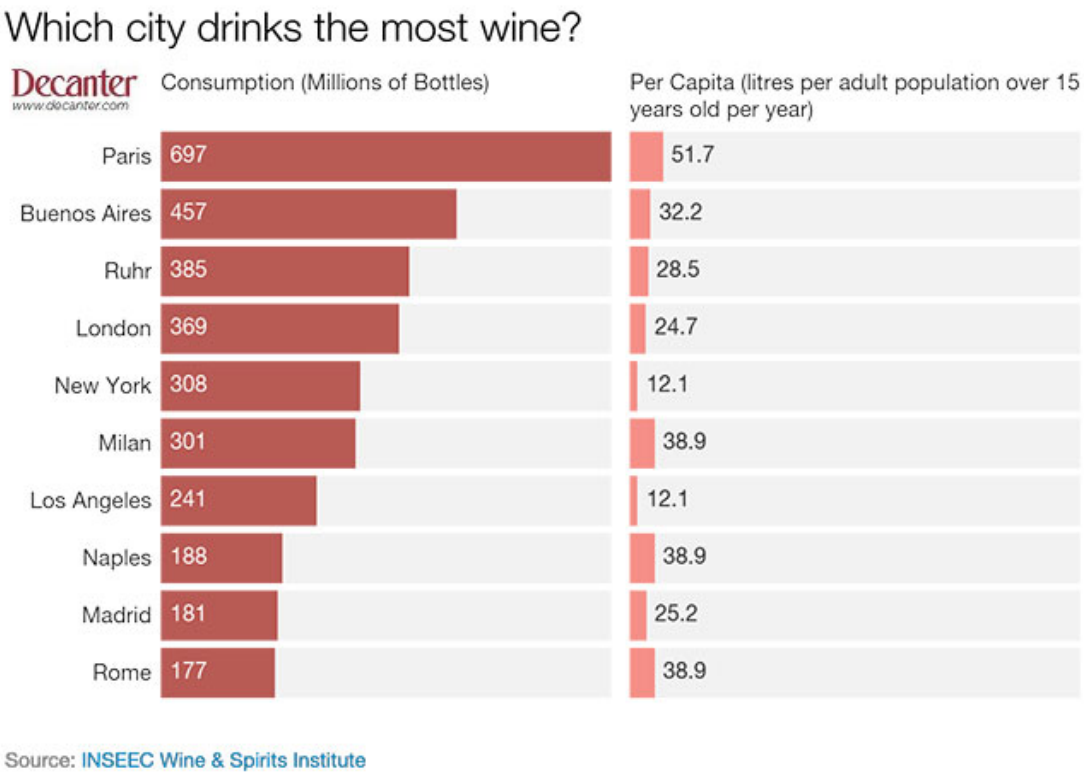
[11] Given that wine contains around 12% of pure alcohol per volume means that that one liter of wine contains 0.12 liters of pure alcohol. This means that 3 liters of pure alcohol equals around 25 bottles of wine.



Source of graphic: Our World in Data
Dataset: WHO, Global Health Observatory (GHO)

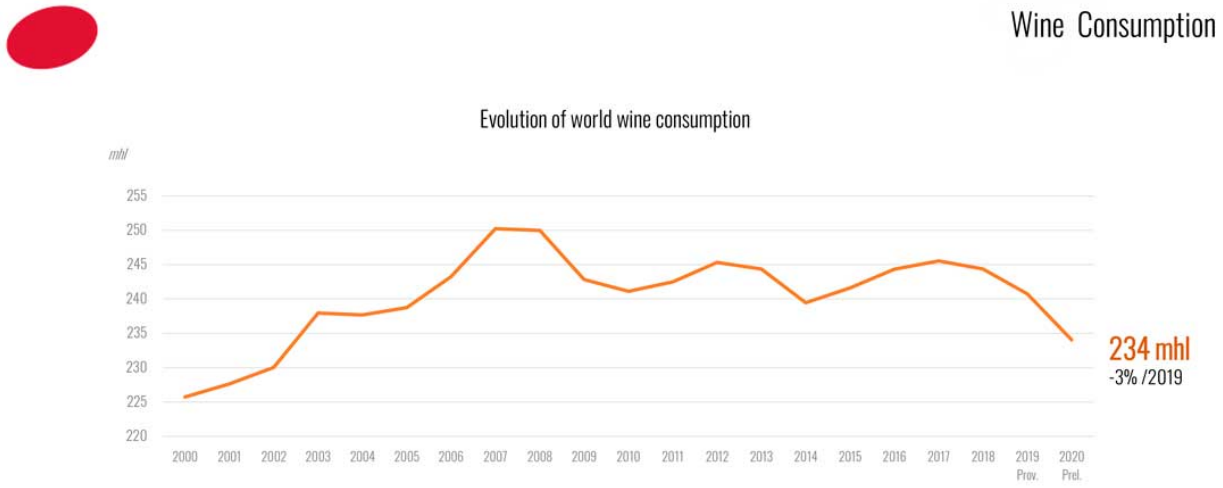
Unsurprisingly, in large cities that generate economic activities and are regularly visited by tourists every year, this average increases even further. For example, a French study calculated that Parisians drink the equivalent of 697 million bottles of wine per year - which is almost 69 bottles per person over the age of 15 on an annual basis. To contextualize these results, it's also worth stressing that Paris hosts many tourists throughout the year - many of whom combine wine and business/travel activities. Given their population densities and the amount of wine consumed in the UK and US in general, London and New York were also high on the list, and came fourth and fifth, respectively, preceded by Buenos Aires and the Ruhr industrial zone of Germany (grouped as one urban entity). Italian cities such as Milan, Naples and Rome also ranked in the top 10 and would have finished right behind Paris if one looks at a per capita basis (i.e. liters per adult population over 15 years old per year).[12]

[12] (Mercer, 2016)



Source of graphic: Mercer, 2016
Dataset: INSEEC Wine & Spirits Institute

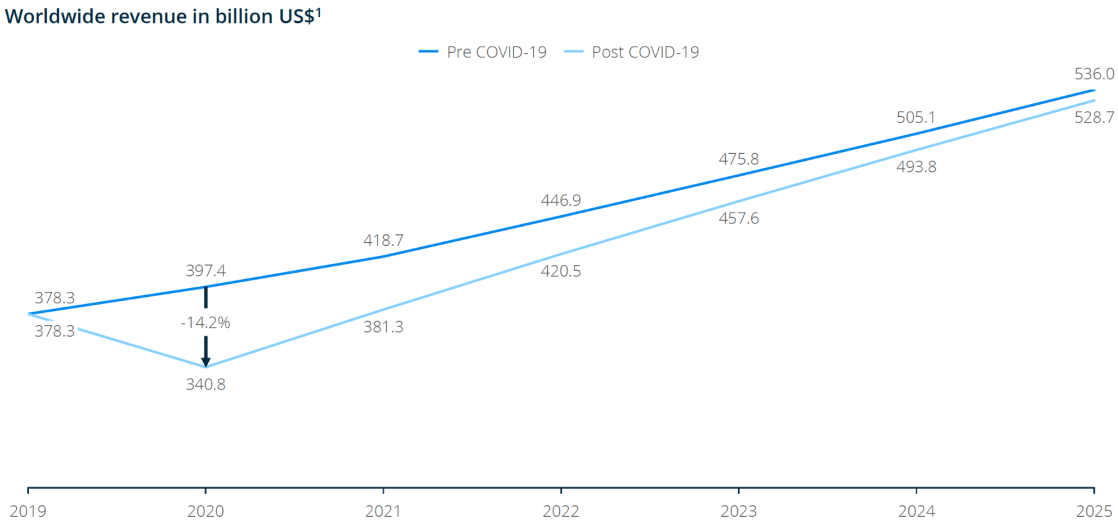
At a global level, wine consumption worldwide was estimated to amount to 234 million hectoliters in 2020, down from 241 million hectoliters in 2019 (equivalent to a 3% decrease compared to the previous year). This means that every minute, 60,000 bottles of wine are consumed in 2020 all around the world, a figure that has significantly decreased compared to 2008, when every minute, 63,000 bottles of wine were consumed all around the world. Most of this decrease can be attributed to the COVID-19 pandemic. While this is the lowest recorded level of wine consumption since 2002, given the uncertainty that has characterized the 2020 year, the figure suggests that the wine sector has altogether not underperformed compared to other commodities. While many observers in the wine industry have pointed out that this recent drop shares many similarities with the 2008-09 global financial crisis, it's worth noting that this was also the third consecutive year of decreasing wine consumption at a global level. However, the OIV indicates that given the margin of error in tracking global wine consumption, these figures should be cautiously considered.



Source of graphic: Karlsson, 2022
Dataset: OIV, 2020

In terms of worldwide revenue (in billion US$), due to COVID-19, the 2020 forecast for the wine segment is 14.2% lower than the original forecast (see below). Even if global wine consumption figures should be used with caution, several wine market analysts anticipate that wine consumption is likely to rebound and increase in the coming years, and therefore anticipate a higher wine consumption during the years following the peak of the COVID-19 pandemic.[13] This is because wine is an integral part of European cultures and this cultural trend is increasingly gaining popularity in various other parts of the world, especially including East Asian and Latin American countries. The young and working-class people in these regions are increasingly incorporating wine in their diet, house parties, and occasional drinks. Such consumer trends are expected to fuel the market growth over the coming years according to several trend forecasting observers.[14]

[13](Karlsson, 2022)
[14] (Grand View Research, 2021)



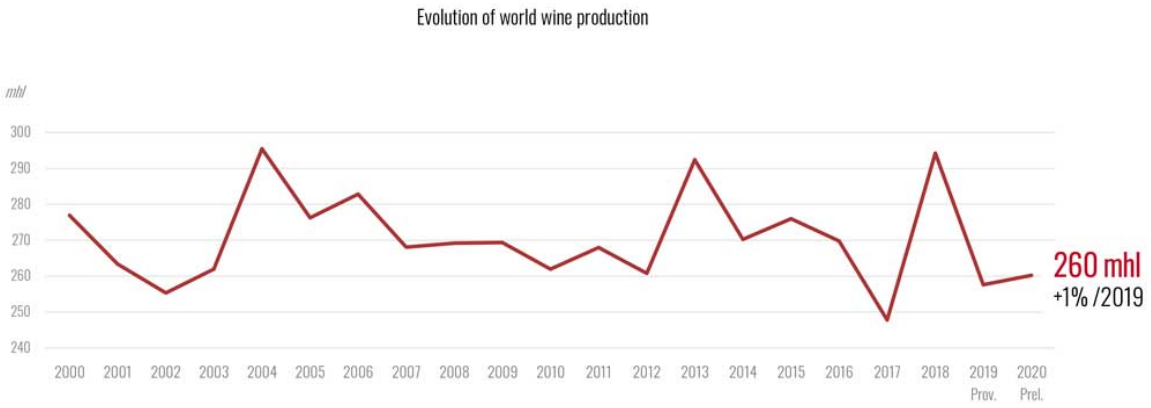
Source of graphic: Shaulova & Biagi, 2020
Dataset: Statista Consumer Market Outlook 2020

However, while further expansion in terms of demand is anticipated in the coming years, several concerns about the future of the wine industry persist. For example, how is the supply side likely to respond to sustained demand and reinvigorated wine 'appetite' from consumers all around the world once COVID-related disruptions are lowered? Is it possible to continue sustaining the same level of current wine production levels without putting at risk quality concerns and/or existing cultural traditions? While consumption trends fluctuate based on the socio-economic context of a given year, what are other factors of uncertainty that are likely to hamper wine production activities?

Global Wine Production

Large-scale wine production, combined with targeted marketing and enhanced export possibilities, has seen a rapid development in the past few decades, resulting in increased consumption patterns overtime (as seen in the previous section). In 2020, the world's wine production increased compared to 2019 to reach 260 million hectolitres, a figure that is slightly below the long term average.[15] While the global supply of wine is working hard to meet the growing demand of an expanding base of consumers (particularly in emerging markets), the wine industry has also had to manage with new forms of climate-related shocks with varying levels of intensity and characteristics that were not seen previously.[16]

[15] Globally, wine production amounted to approximately 279 million hectoliters in 2000. By 2010, that figure had decreased to about 264 million hectoliters. However, wine production increased again in the following decade, reaching approximately 292 million hectoliters in 2018.
[16] (Karlsson, 2022)



Source of graphic: Karlsson, 2022
Dataset: OIV, 2020

In terms of harvest, since 2000, there have been three very important years for the wine industry which were 2004, 2013, and 2018, during which the overall global wine production reached 290-295 Mhl. The smallest production over this period was in 2017 when it was below 250 Mhl, and the second smallest was 2002 which reached only 255 Mhl. This was partly because of the spring frosts which damaged a sizeable These figures are important in the context of climate change because the size of the variation between the smallest and largest global wine production figures is just over 45 Mhl - which is equivalent to a variation of around 8-9% around the average (with a total amplitude of approximately 17%). This is significant because several observers attribute the size of this “swing” to the growing uncertainty of extreme weather patterns.[17]

At a country level, Italy is still the largest wine producing country, followed by France and Spain. While the harvest has been both abundant and of excellent quality in Europe in recent years, the production was artificially depressed due to EU-related regulations, but was still up. In the rest of the world, many countries saw a decline in wine production, including China.[18] Below are the top ten wine producing countries in the world (2020 data):

[17] (Karlsson, 2022)
[18] Ibid.

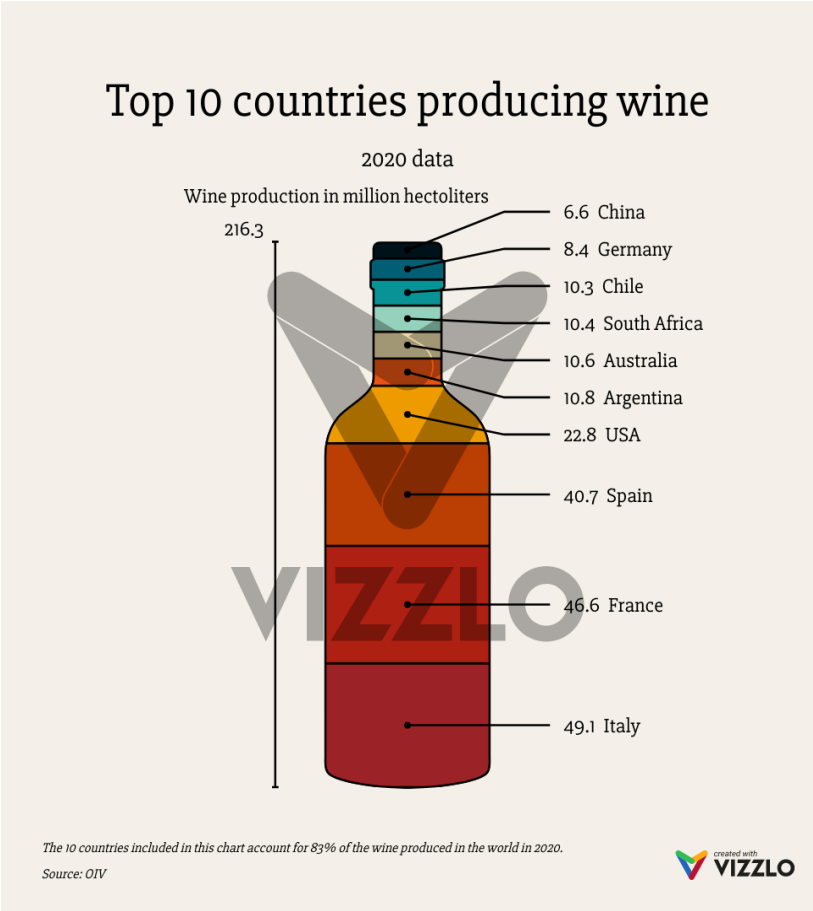
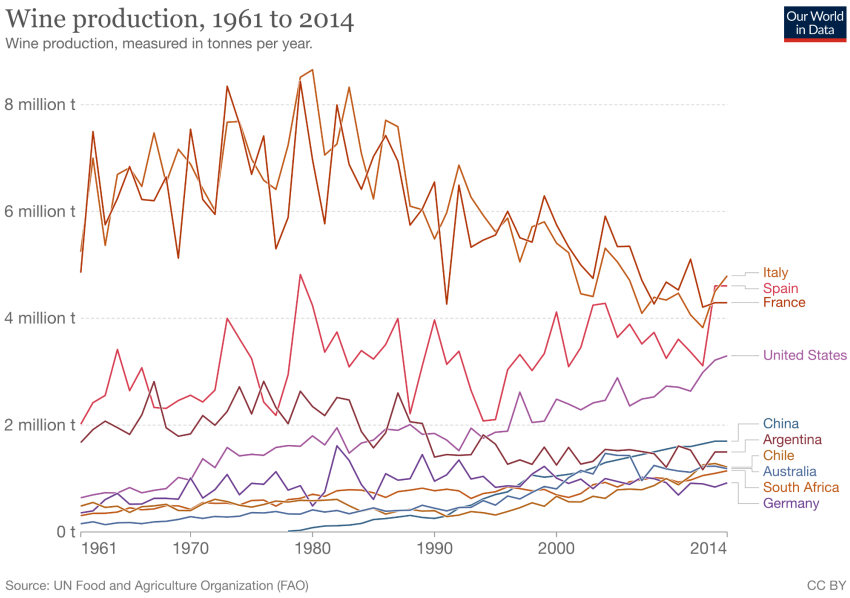


Chart generated by thesis author.
Dataset: OIV, 2020

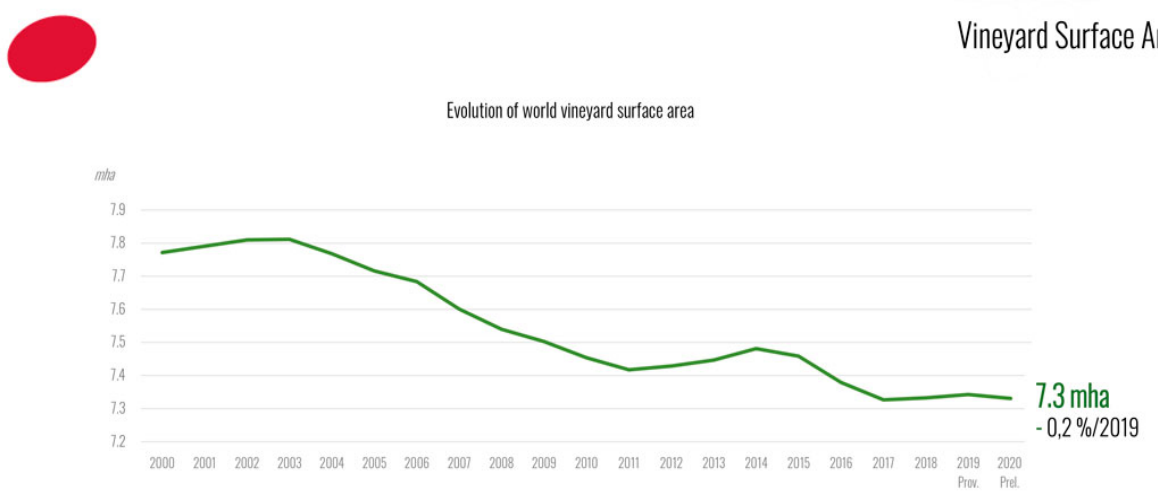


Source of graphic: Our World in Data
Dataset: UN Food and Agriculture Organization (FAO)

Global Vineyard Surface Area

The climate, terrain, and soil quality in which the wine grapes are grown has a major influence on how the wine turns out. Though most of the world's wine is grown in the Mediterranean region, or in areas with a Mediterranean climate, the areas in which grapes can be grown have expanded greatly in recent decades, in particular in so-called "New World" countries (Australia, New Zealand, South Africa, Chile, Argentina, etc.).

Although global wine production has seen a net increase over the last two decades, the surface area covered by vineyards has decreased during that same time period. The world's vineyard surface area (the planted surface area) has been slowly decreasing for several years, and the data from 2020 suggest that this trend has been continuing to a certain extent. As of 2020, there are 7.3 million hectares[19] (18 million acres) of vineyards worldwide[20], which include 75% that are solely dedicated to the production of wine. To better contextualize this figure, if today's global wine surface area were a standalone country, it would have the same surface area as Ireland. Since the record years in 2002-2003 when the world vineyard surface area reached over 7.8 Mha (19.3 million acres) - there has been a loss of 6% of vineyard surface area during the past 20 years. Similar to the global wine production trends, disruptive extreme weather events attributed to climate change have played a key role in constraining wine production activities in terms of vineyard surface area.[21]



Source of graphic: Karlsson, 2022

[19] 7.3 Mha is equivalent to 18 million acres.
[20] These numbers include all vineyard acreage, so it includes grapes for wines and juices, table grapes and raisins. It also includes young vines not yet in production.
[21] (Karlsson, 2022)

Dataset: OIV, 2020

At a regional level, while Europe's vineyards have been relatively stable during the past few years at 3.3 Mha - equivalent to 45% of the global total - the rest of the world has declined. The largest wine producing country outside of Europe is the USA and its vineyards have consistently shrunk during the past 7 years (equivalent to 405,000 ha in 2020). Similarly, the South American vineyard surface area has also been shrinking during recent years (Argentina, Chile and Brazil vineyard surface area have respectively decreased by approximately 1%). Other significant countries from the "New World" have also seen their vineyard surface area decline in the past 10 years - especially Australia and South Africa. Experts in the wine industry explain that this has been partly caused by climate change factors (drought and water shortages). For example, South Africa faced a severe drought between 2015 and 2018 which resulted in a loss of 10,000 ha of vineyard overtime.[22]

The previous sub-sections demonstrated that while the wine industry has expanded tremendously in the past 40-50 years and benefited from a sustained demand from consumers all around the world, a closer look at the production and vineyard surface data shows that this industry is also extremely sensitive to the changes in temperature and related seasonal fluctuations that are expected with a changing climate.

The following section illustrates this important principle by looking at recent extreme weather events that have taken place in Bordeaux, France (2017) and in California, USA (2020), and illustrating how these different climate categories are interrelated and how disruptive weather conditions amplify these agricultural risks.

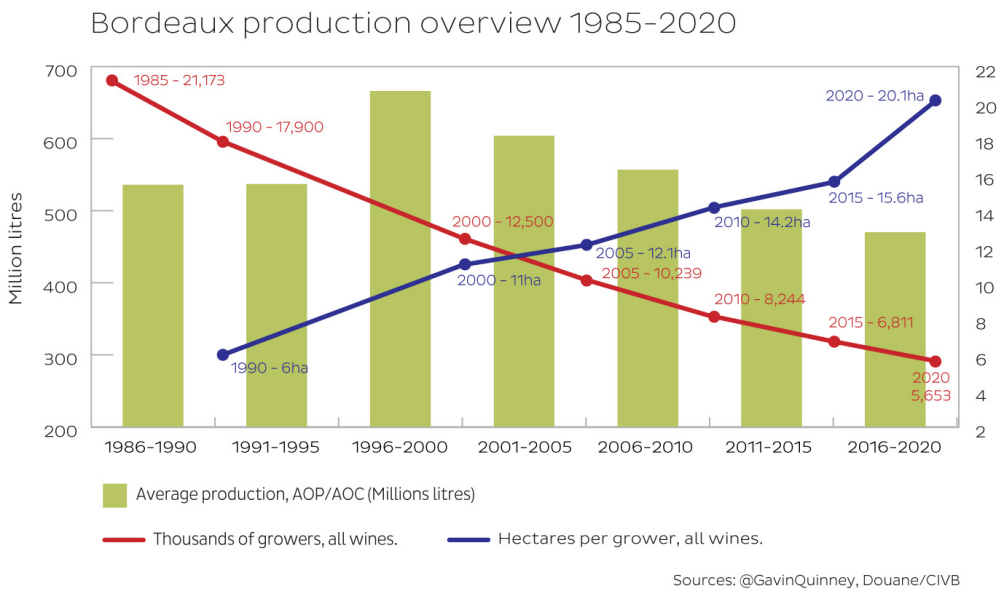
Chapter 2. Key Wine Regions Confronted by Recent Extreme Weather Events

Problems for vineyards attributed to climate change can range from irrigation difficulties to disease to soil erosion due to excessive rainfall, flooding, or prolonged heat. To better understand how unforeseen, disruptive environmental factors (frost, fires, drought, etc.) can suddenly collide with risk winemaking activities, this section focuses in more details on two examples of weather-related disasters: (a) the 2017 spring frosts in the Bordeaux region (France), and the 2020 summer wildfires in California (USA). These two case studies were selected because these weather-related disasters have taken place in wine regions that have been established for a significant amount of time, both regions are strong contributors to the national wine production level in their respective country, and drive economic growth and employment opportunities at a more regional level.

[22] (Karlsson, 2022)

Focus on the “Old World”: Spring Frosts in Bordeaux, France in 2017 (Case study)

The Bordeaux region produces some of the most recognizable wine bottles in the world and is home to more than 8,500 producers (or “chateaux”). With a total vineyard area of over 120,000 hectares, Bordeaux is also the largest wine growing area in France. Average yearly vintages produce over 600 million bottles of wine, ranging from large quantities table wine, to some of the most expensive and prestigious wines in the world. The vineyards are spread across 54 official appellations of Bordeaux wine, and the wine production generates more than $2 billion in annual export revenues and therefore contribute significantly to France’s commercial activities.[23]

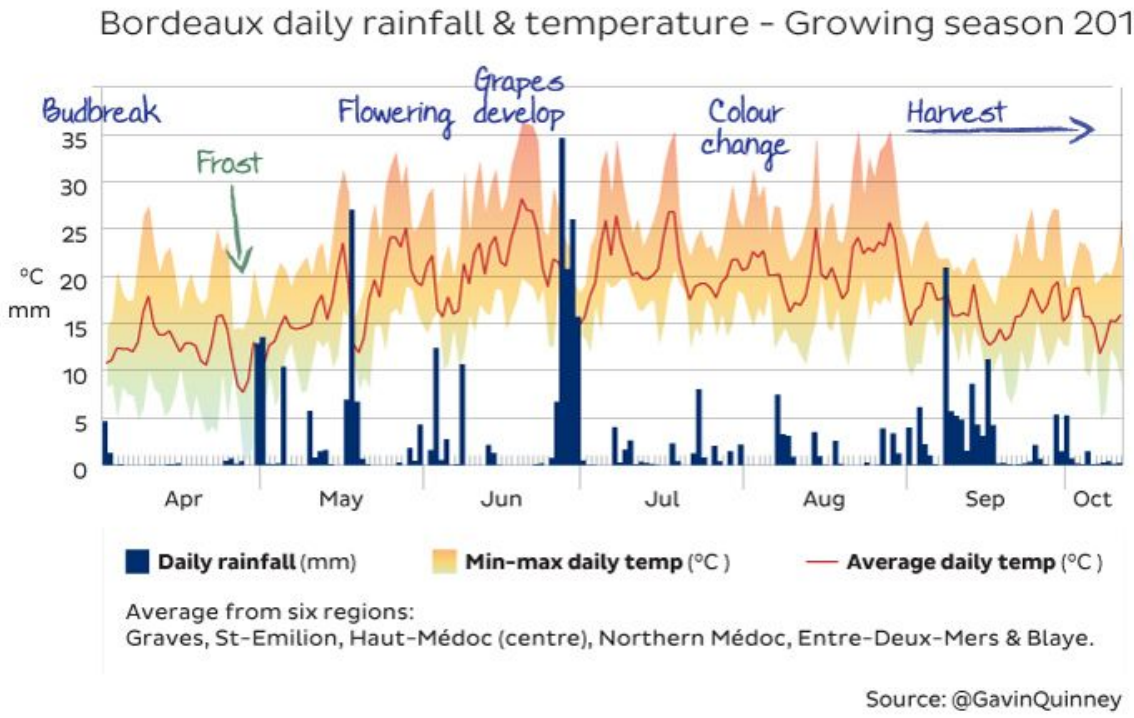


Source of graphic: Currin, 2021

Since 1950, average temperatures in Bordeaux have risen 2 degrees Celsius, or 3.6 degrees Fahrenheit, according to France’s meteorological service Météo-France. The resulting summer heat is baking Bordeaux’s vineyards, making an area that borders the Atlantic Ocean feel increasingly Mediterranean.[24] However, in regions like the Bordeaux region, the unpredictable nature of climate change can also facilitate reverse weather phenomena and bring occurrences of frosts that may occur outside of the usual winter periods. Unseasonal frosts are detrimental to the winemaking process as they cause lower yields and directly affect grape quality due to the reduction of bud fruitfulness. When this happens, vineyards in low-lying areas, where cold air settles, are more susceptible to frost than sloped vineyards or higher plateaus.[25]

[23] "Synopsis of Bordeaux wines" (PDF). Vins de Bordeaux (CIVB). 2009. Archived from the original (PDF) on 24 July 2011.
[24] (Bajak, 2018)
[25] (Castaing, 2017)

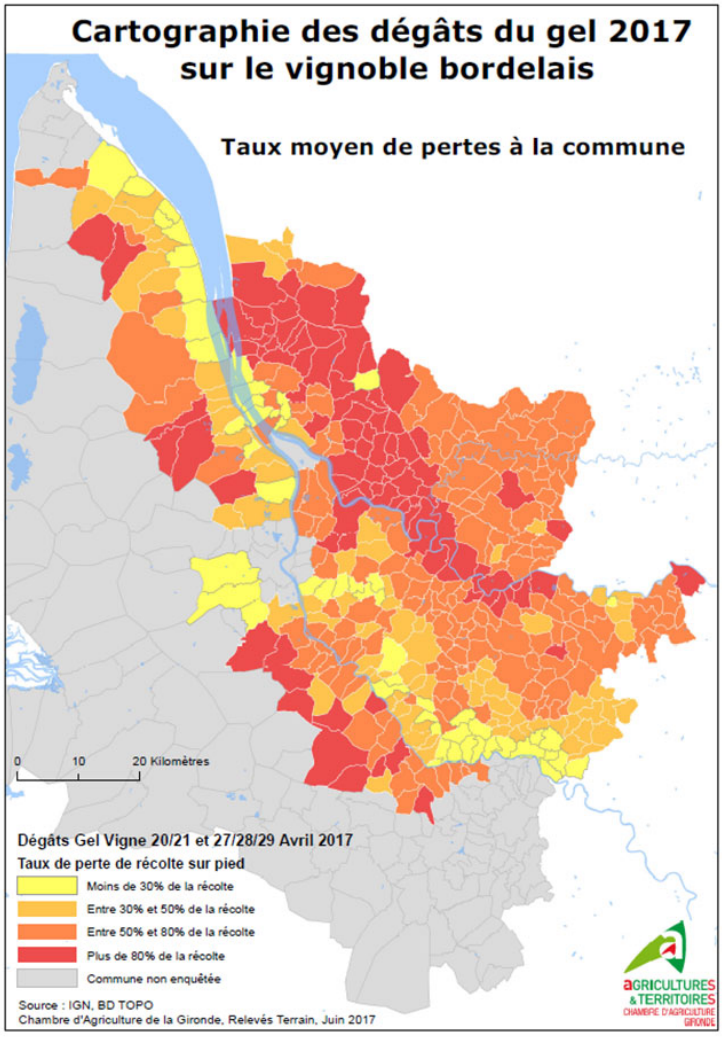
During a 3-days period in April 2017, the plummeting temperatures of an unseasonal frost were responsible for decimating up to 40% of crops in the Bordeaux region - representing the equivalent of 240 million liters of wine with a financial toll that reached approximately 1.6 billion euros according to the CIVB (Conseil Interprofessionnel du Vin de Bordeaux or Bordeaux Wine Council).[26] This is significant in a country where the wine industry represents nearly 600,000 jobs (including 142,000 wine growers and 3,000 sommeliers) and where 10,000 tourist-oriented wine cellars attract more than 10 million visitors every year (including 40% of foreigners).[27]



Source of graphic: Currin, 2021

As seen in red on the map, in several areas located on the Right Bank for example, vineyard losses were 80%. Given the size of the damage, several chateaux even announced that year that they were not putting any wine in bottles for that harvest year. The damage caused by this severe cold spell damaged vineyards in Bordeaux and elsewhere in France so much that the annual French wine product ended up being the lowest in the last 60 years.[28] As seen in the previous section, the sudden decrease of wine production in France (especially in Bordeaux) had a domino effect on the level of global wine production, which was recorded as the lowest since 1957 (the EU's wine production also dropped by 14.6% to 141 million hectoliters). [29]

[26] (Currin, 2021)
[27] For more information: https://www.businessfrance.fr/Media/Default/PROCOM/Kits/Agroalimentaire/Business_France-Wine_Industry.pdf
[28] (Anson, 2018)
[29] (de La Hamaide & Denis, 2018)



Source of map: Gironde Regional Chamber of Agriculture (Anson, 2018)
Dataset: Gironde Regional Chamber of Agriculture

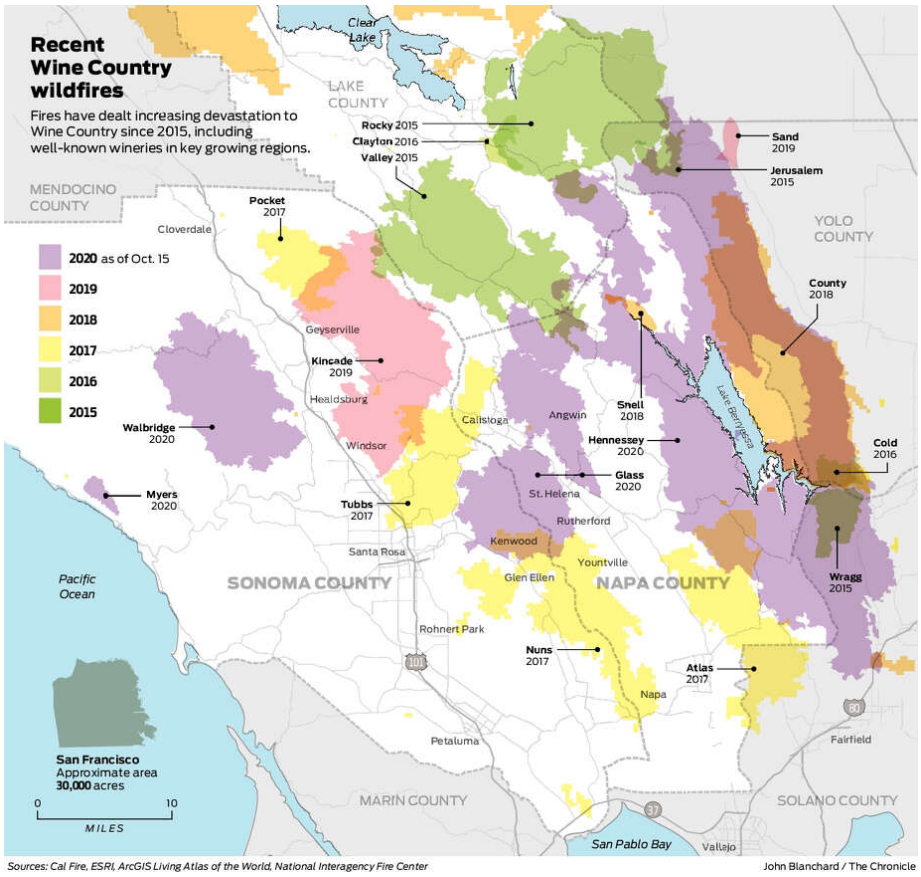
After looking at the sudden impacts of spring frosts in the Bordeaux wine region in 2017 and the industry-level domino effect this type of climatic disruption can have on the wine industry (within the EU but also at a local level), we examine in a similar way the different ramifications of the wild fires and the impact of persisting drought episodes in California's wine producing areas.

Focus on the "New World": Recent Devastating Wildfires in California, USA (Case Study)

Similar to the Bordeaux region in France, key areas in California such as Napa or Sonoma are also known for producing prestigious wines that are consumed all over the world.[30] Moreover, it's worth noting that California produces about 90% of the American wine supply and is considered as the 4th largest wine producer among the world's independent nations. As of 2020, California continues to be the state with the largest number of wineries, with 1,991 wineries - ranging from home-grown and small boutiques to larger corporations with international distribution networks.[31] Another area that shows the significant economic contribution of California's wine industry is the fact that it holds the most winery jobs in 2020 (36,001) in the USA, followed by - again - Washington (4,190) and Oregon (3,310).[32]

However, according to a study led by Sonoma State University which aggregated data on climate change and its impact on the wine industry worldwide, California may lose nearly 50 percent of current acreage for premium grape growing within the next 50 years.[33] This is because this wine region has been increasingly exposed to extreme weather conditions in the last few years, including droughts, heatwaves, and wildfires - natural hazards that are all too often interlinked. For example, droughts, which are characterized as imbalances between evaporation and precipitation flows, are a major cause of wildfires in California. As climate change brings hotter and drier conditions, and as temperatures around the globe are increasing, evaporation will continue to increase and accentuate conditions for further drought scenarios and drier conditions for wildfires. According to the 2018 Napa Vintage Report, between 1895 and 2018, California warmed an average of 2.3 degrees Fahrenheit during the wine-growing season.[34] To make matters worse for vineyards, the Los Angeles Times also reported that California is seeing less fog overtime, which increases heat levels generated by the sun, forcing grapes to ripen too quickly on the vine, lowering their acidity and increasing their sugar, which makes for wines that taste flat and are less dynamic in the glass. This means that it will be harder for winemakers to obtain a good acid-sugar ratio, pH balance, color and flavor just right - which means that the original taste of several grape varieties such as the Cabernet Sauvignon, could be altered on a permanent basis.[35]

[30] In California, there are over 107 American Viticultural Areas (AVAs), including the well-known Napa, Russian River Valley, Rutherford and Sonoma Valley AVAs.
[31] Washington had the second largest number of wineries in the USA in 2020, at 435.
[32] (US Bureau of Labor Statistics, 2021)
[33] (Brissette, 2020)
[34] (Prelle, 2022)
[35] (Ledsom, 2020)



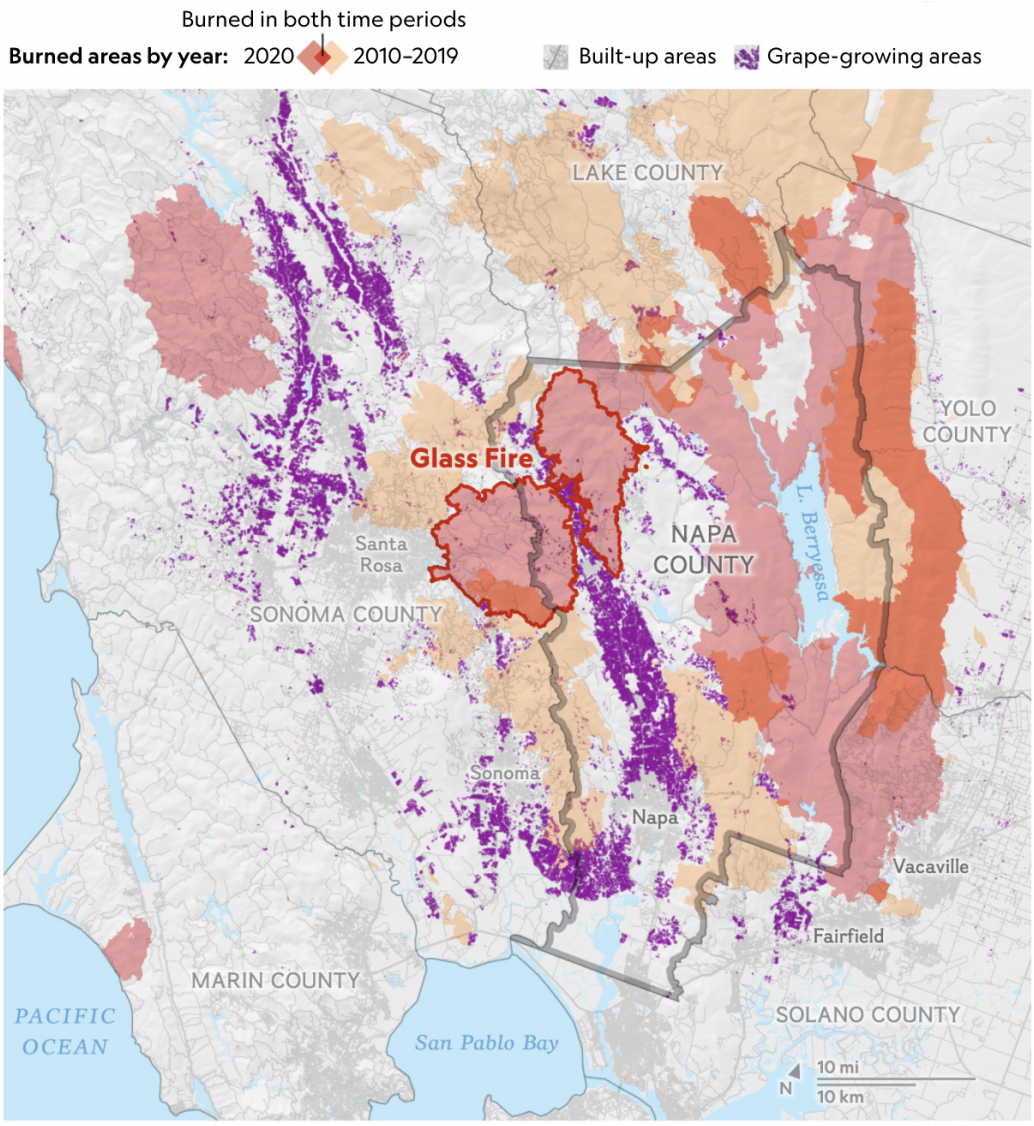
Source of map: Blanchard and Morris, 2020
Dataset: Cal Fire, ESRI, National Interagency Fire Center

Moreover, heavy smoke from wildfires is not only a hazard to agricultural workers but can also spoil grapes. This is because a grape that ripens later due to drought conditions also stays on the vine much longer, putting it at a higher risk of wildfire-induced smoke taint, which can then penetrate the grape's skin and give the wine a smell and flavor of an ashtray or a campfire. In other words, grapes that escape the flames can absorb chemicals from smoke flows that ruin their taste, leaving the dreaded “smoke taint” - a feature that winemakers complain about and describe as an “ashy finish”.[36] Several parts of the grape-growing county of Napa have burned multiple times over the past decade. The intensity and scale of wildfires has been described as “staggering” by wildfire scientists given the blend of changing rain patterns, warmer air patterns, dry forests and fire suppression. In 2020 alone, Napa Valley lost about $2 billion from damages relating to wildfires. It’s also worth noting that five of the twenty largest wildfires in California history were part of the 2020 wildfire season.[37]

One of the fires that deeply damaged wine country in 2020 was the Glass Fire that hit the northern end of Napa Valley in mid-September and damaged at least 26 wine and vineyard

[36] (Madhusoodanan 2021)
[37] (Mobley 2020)

properties. But the entire growing season along the West Coast was one extreme: a mild winter led to early bud break, followed by record-setting heat waves that sent temperatures soaring above 100 degrees for several days in August. In some areas, grapes were sunburned before they could be affected by smoke taint. The heat fueled lightning storms that ignited wildfires in California, Oregon and Washington in August.[38]



RILEY D. CHAMPINE, NG STAFF;
SOURCES: ESTHER MOBLEY, SAN FRANCISCO CHRONICLE; U.S. CENSUS BUREAU; USDA

Source of graphic: Mobley, 2020

[38] (McIntyre 2020)

Chapter 3: Potential Climate Change Impacts That Could Affect the Wine Industry

The previous sections explored how the wine industry has expanded during previous decades before focusing on two examples where extreme weather events caused by climate change heavily damaged vineyards in Bordeaux (France) and in California (USA), while instilling a sense of uncertainty within the industry. After looking at these examples in more detail, one might wonder how many more similar cases exist in the world of winemaking and what type of viticulture challenges they are likely to face in the future as a result of intensifying global warming.

The Importance of "Terroir" in Winemaking (Climate + Soil + Variety Equilibrium)

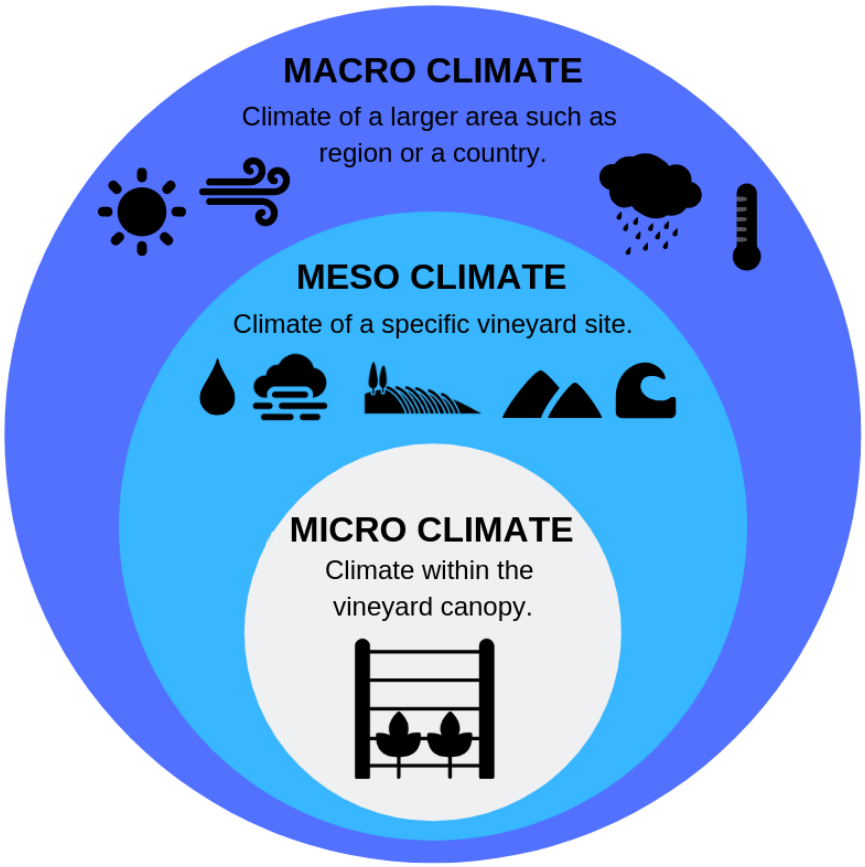
All agricultural activity is dependent upon and interconnected to climate and weather; grapes are no exception.[39] Climate is the most important ingredient for winemaking since it influences the suitability of certain grape varieties to a particular region as well as the type and quality of the wine that will be produced as a result.[40]

In fact, several agricultural experts explain that wine grapes are fascinating climate specimens to study as they are one of the most sensitive crops to variations in temperature and precipitation that currently exist. The expression "canary in the coal mine"[41] is often used to describe the important role that wine grapes can play in understanding the effects of climate change on agricultural crops. This also means that, due to its high level climate sensitivity, wine grapes can also act as an indicator or even an early precursor of possible adverse conditions or dangers that are likely to happen to similar agricultural products in the future.[42] As such, any alteration in climate and weather patterns is sufficient to affect grapes and the subsequent production of wine.[43]

From a viticulture perspective, it is essential to distinguish different types of climate dynamics. As seen in the illustration below, it is not sufficient to only focus on the macroclimate (i.e. the climate of a given region or large geographical zone). The climate, in general, is important, but it typically applies to an entire region. Within that region, there are smaller microclimates that have their own temperature variations. Those small differences in temperature can dramatically affect the grapes that are grown in that smaller region. These microclimates can come from such

[39] (McGuire, 2016)
[40] (Gladstone, 2011)
[41] The "canary in the coal mine" expression refers to the former practice of taking caged canaries into coal mines. The birds would die if methane gas became present and thereby alert miners to the danger.
[42] (Rice, 2020)
[43] (McGuire, 2016)

factors as the proximity to an ocean or other bodies of water and the presence of mountains to the slope or orientation of a vineyard.[44] In fact, wine production is largely dependent on the *mesoclimate* (i.e. the climate of a vineyard) and the *microclimate* (i.e. the environment of a small restricted space, for example a vineyard canopy), and this means that for high quality wines to be produced, a fragile but essential climate-soil-variety equilibrium needs to be maintained at all times. The complex interaction between climate, soil and grape variety is likely to be significantly altered in the coming decades and will come under threat due to the emerging effects of climate change.[45]



Source of illustration: Krajnc, 2019

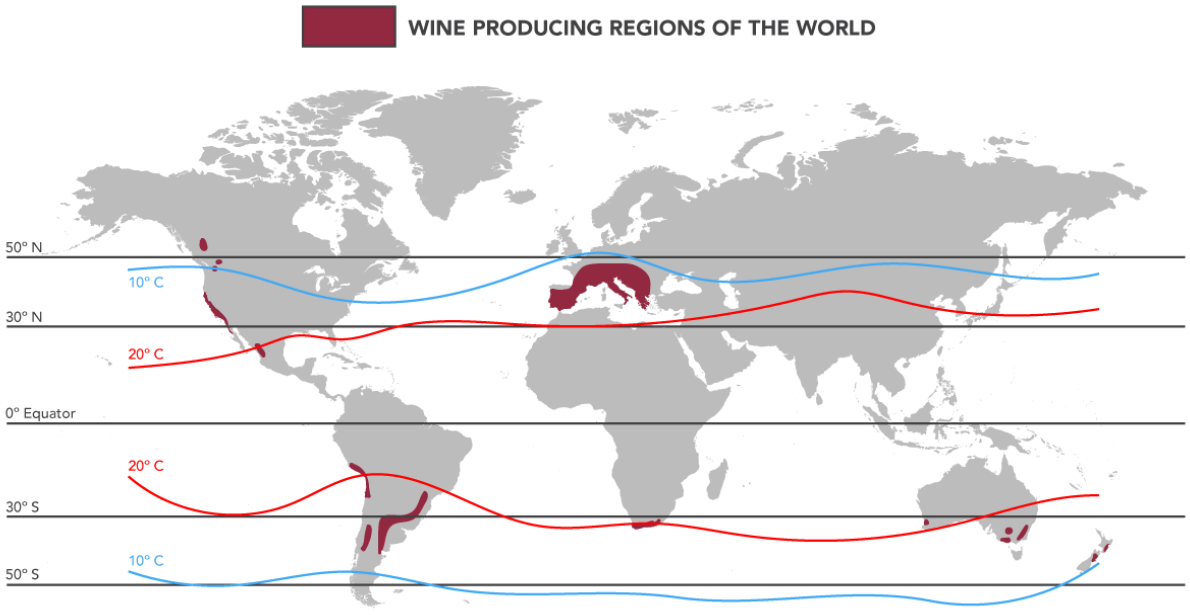
Where in the world could wine continue to be produced in the future?

As seen in the previous sub-section, understanding the different levels of climate dynamics is vital because wine composition is largely dependent on *mesoclimate*, the climate of a vineyard,

[44] (Allie, 2020)
[45] (Krajnc, 2019)

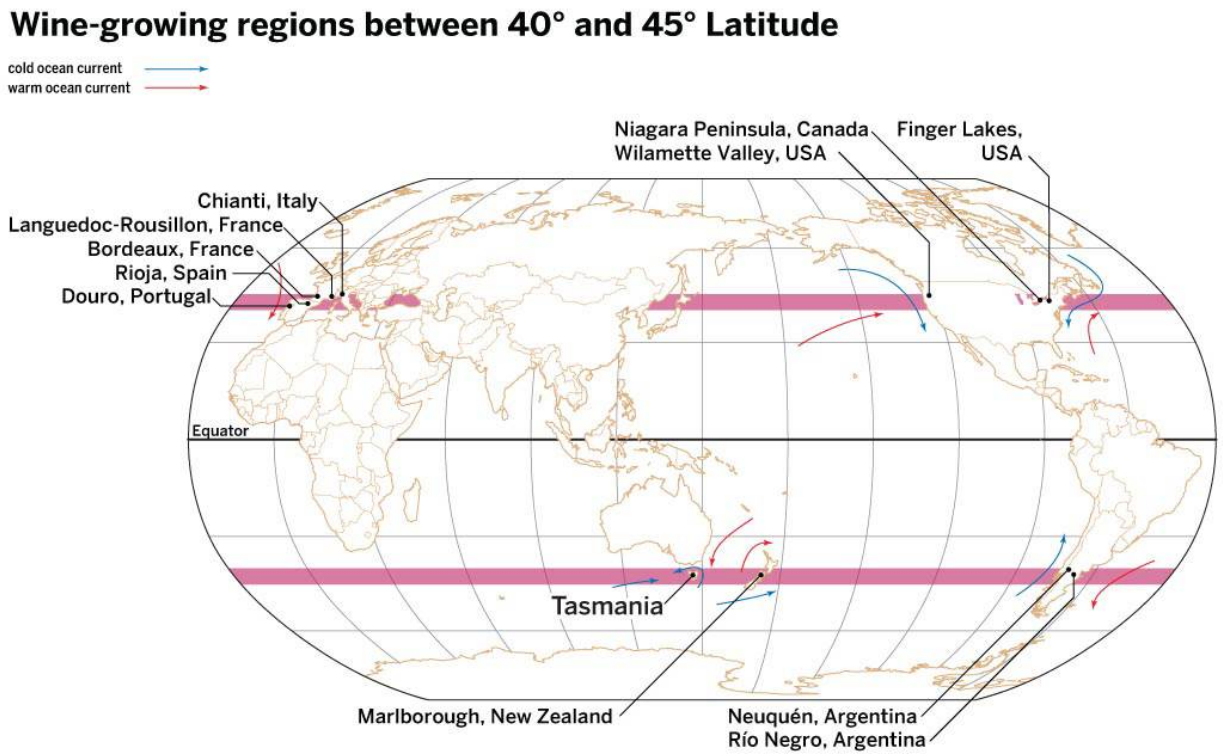
and *microclimate*, the environment of a small restricted space such as a row of vines. Moreover, the quality of premium wine production is contingent only within very narrow climate ranges. Despite the fact that climate modeling is a notoriously difficult process fraught with a variety of caveats and complex assumptions (and not all predictions agree on which global warming scenario lies ahead), there are still broader patterns that are important to flesh out and that seem to become increasingly easier to notice.

Grapevines thrive in temperate regions where a long warm growing season will allow them to develop. Grapevines only grow between the 30th-50th parallel. Not because countries or regions outside those boundaries don't appreciate wine or don't know how to grow it. It is just simply either too hot or too cold for grapevines to survive in their climate. Grapevines start to grow when the temperature reaches above 50°F, anywhere below that they remain dormant. When temperatures begin to rise into the 63°-68°F range the vines will begin to flower. It is these flowers that will eventually become the grapes.[46]



Most of the grapes for wine production are grown in climates located between the 30th and 50th parallel on the northern and southern hemisphere. Source of map: Allie, 2020

[46] (Allie, 2020)



Wine grapes grow almost exclusively between 30 and 50 degrees latitude north and south of the equator. Source of map: The Wine Lab

Worldwide, a shift from traditional, notorious wine-producing areas to much lesser known wine producing regions is predicted. While some studies have indicated that initial climate change could prove beneficial for emerging wine growing regions, excessive climate change is expected to be disruptive for traditional wine regions given that climate change is forcing winemakers to move further from the Equator. For example, Tasmania and parts of the South Island of New Zealand are expected to assume greater importance in Australasian fine wine production, while in Europe southern England is projected to become more significant (assuming these vineyards can compete with other forms of land use). In hot, dry regions like Portugal and southern Spain, wine production has already begun the move to higher elevations. Moreover, some in the wine industry predict that significant portions of California, France, Spain, Portugal, Australia and South Africa will become too hot and dry to produce quality wines by 2050

Below is a summary table of potential, forward-looking scenarios for the wine industry due to climate change:

Climate Projection for Wine Industry	Geographical Zone	Source

One study published in 2013 predicted that ***by 2050, two-thirds of today's wine regions may no longer have climates suitable for the grapes they grow now***.	Global	*Hannah et al., 2013*
(...). Warmer temperatures generally yield larger harvests and expedite ripening, producing grapes with more sugar and bold flavors and wine with higher alcohol content. But if global temperatures soar past 3.6 degrees Fahrenheit by 2100 (which seems very likely), ***the land suitable for growing wine grapes could shrink by more than half.***	Global	*Liptak, 2020*
Gregory Jones, a climatologist (University of Oregon), estimated that in the Northern Hemisphere the broad geographical swaths of territory suitable for winemaking ***will move northward by 275-550km over the next 100 years.***	Northern Hemisphere	*Jones & Webb, 2010*
The United Nations has predicted that viticulture as a whole in the Northern Hemisphere might ***move an average of up to 111 miles (180 kilometers) farther north*** compared to where grapes are growing now. If this trend continues, it could spell financial ruin to long-established wine businesses, while presently less likely areas could economically benefit from diversifying into the wine market.	Northern Hemisphere	*Deutsche Welle, 2019*
Recent studies show that the northern frontier of vine cultivation in Europe could ***advance by 20-60km each decade between now and 2050*** while others predict the rise of whole new wine regions.	Europe	*The Economist, 2019*
The gradually increasing temperatures will lead to a shift in suitable growing regions. It is estimated that ***the northern boundary of European viticulture will shift north 10 to 30 kilometers (6.2 to 18.6 mi) per decade up to 2020 with a doubling of this rate predicted between 2020 and 2050***. This has positive and negative effects, as it opens doors to new cultivars being grown in certain regions but a loss of suitability of other cultivars and may also risk production quality and quantity in general.	Europe	*Kenny & Harrison, 1992*

Vineyards may be displaced geographically beyond their traditional boundaries ("terroir" linked to soil, climate, and traditions; Metzger and Rounsevell, 2011) and, in principle, wine producers could adapt to this problem by growing grape varieties that are more suited to warmer climates. Such technical solutions, however, do not account for the unique characteristics of wine production cultures and consumer perceptions of wine quality that strongly affect the prices paid for the best wines (White et al., 2009; Metzger and Rounsevell, 2011).[47]

[47] (Kovats et al. 2014)

Chapter 4. The Future of the Wine Industry: Emerging Opportunities and Other Promising "Glocal" Practices[48]

As mentioned previously, the effects of climate change are already being felt in several wine regions. As a result, a variety of actors ranging from governments to vineyard owners to climatologists are working to respond to the challenges brought on by climate change.[49] To mitigate these effects, it will be necessary for the wine industry to invest in strategies and practices that will allow the continued production of high quality wines at economically acceptable yields. Ultimately, the effectiveness of any strategy depends on growers having the options and resources to adapt at a local scale, and on reducing greenhouse gas emissions and limiting warming globally.[50]

However, while grape production is highly sensitive to climate, production (of grape varieties) is still strongly culturally dependent and adaptation is potentially limited by the regulatory context in a given country or region. For example, an additional barrier to adaptation is that wine is usually produced within rigid, regionally specific, regulatory frameworks that often prescribe, among other things, what grapes can be grown where, for example, the French AOC (Appellation d'Origine Controlee) or the Italian DOC (Denominazione di Origine Controllata) and DOCG (Denominazione di Origine Controllata e Garantita) designations. Suggestions have been made to replace these rigid concepts of regional identity with a geographically flexible "terroir" that ties a historical or constructed sense of culture to the winemaker and not to the region (White et al., 2009).[51]

Switching wine grape varieties could come with significant — but not insurmountable — legal, cultural, and financial challenges. Yet, growers will still need to learn how to grow these new varieties in regions that were used to the same varieties for hundreds of years and consumers who are willing to try new varieties, possibly outside of their favorite wine regions.[52] For winemakers, adaptation to a changing climate will therefore involve a lot of innovative work and flexibility - including testing, experimenting and refining.[53] Several measures are gaining traction - below, listed in a summary table, are examples of emerging adaptive measures that winemakers are considering in different wine regions.[54]

[48] In this context, "glocal" means reflecting or characterized by both local and global considerations.
[49] (McGuire, 2016)
[50] (Fecht, 2020)
[51] (Kovats et al. 2014)
[52] (Fecht, 2020)
[53] (Kovats et al. 2014)
[54] Information needed to compile this summary table originated from the following sources: Citranglo, 2021; Kovats et al. 2014; Fecht, 2020; Asimov, 2019.

Implementation Timeline	Category of measure	Technical entry point	Adaptive Measures
Short-Term	***Agriculture***	Canopy	Late Pruning Shoot Trimming Leaf Removal
		Irrigation	Dry Farming Partial Root Drying Deficit Irrigation Drip Irrigation Water Reuse Water Reservoir Water Spraying
		Harvest Management & Post-Harvest Management	
		Soil Management	Cover Crop Biochar Mulching Mycorrhiza Anticipating Insect-Borne Diseases
Long-Term	***Scientific Tools***	Plant Material	Drought-tolerant grape variety Drought-Tolerant rootstock Late Ripening Variety
		Vineyard Design	Land Leveling Training System Row Orientation Shading Elevation & Sunlight Vineyard Density Minimal Pruning
	Legal & Cultural Changes	Site Selection	Land Use Reforms Migration or Relocation Flexibility with Geographical Label
		Farm Strategy	Insurance Hazard Monitoring Wine Diversification

Yet it's not just vineyards that need to make in-depth changes. Given all the challenges related to growing wine grapes, consumers will also need to adjust their preferences and expectations. Similar to the winemaker's summary table, a short summary table is displayed here to provide potential wine consumption trends that could emerge in the future because of climate change.

What consumers could expect as a result	Type of new experience	Constraint or Advantage
“Tasting”	More variety in flavors and aromas?	Advantage
	Higher alcohol on average?	**It depends**
	More natural/organic wine become available?	Advantage
“Buying”	More marketing expected around lower-alcohol content wines?	Advantage
	Recurring supply chain issues?	**Constraint**
	Higher pricing per unit due to shifting supply flows?	**Constraint**
	More eco-friendly packaging to encourage circular economy?	Advantage
“Discoveing”	Increase in organic/sustainability certification processes?	Advantage
	New wine tourism destinations?	Advantage
	Unusual new wine regions become more mainstream?	Advantage
	Less wine waste, more wine-based products?	Advantage

Conclusions & Considerations for Further Work

This work aimed at “bridging” two thematic domains that are not necessarily connected in popular discourse: the wine industry and climate change. While the topic of climate change in the wine industry tends to attract much media and academic attention and generates important discussions within the industry, most of the existing evidence is either geographically localized, confined to a specific grape variety, or difficult to understand for wine *aficionados*. This project provided a “glocal” glimpse into the wine industry, by using geovisualization and storytelling tools to help readers better grasp which wine regions are already highly exposed to climate risks. A closer look at extreme weather events that recently impacted the “Old World” and the “New World” was provided to contextualize these macro-level shifts, before finally, exploring different opportunities and adaptive changes the wine industry might go through as a result.

To that aim, there is still some further follow-up work not yet realized within the timeline of this thesis semester. Some are highlighted below and will be hopefully added to enrich the visualization in the next few months.

One key aspect not taken into account yet involves the irrigation dimension. For example, the issue of irrigation is managed very differently in the US from the European Union, which is something that not only complicates current winemaking activities but could also unlock a wide range of adaptive measures in the future. My goal is to identify ways to visualize and quantify these irrigation parameters that would be of significant value to this project.

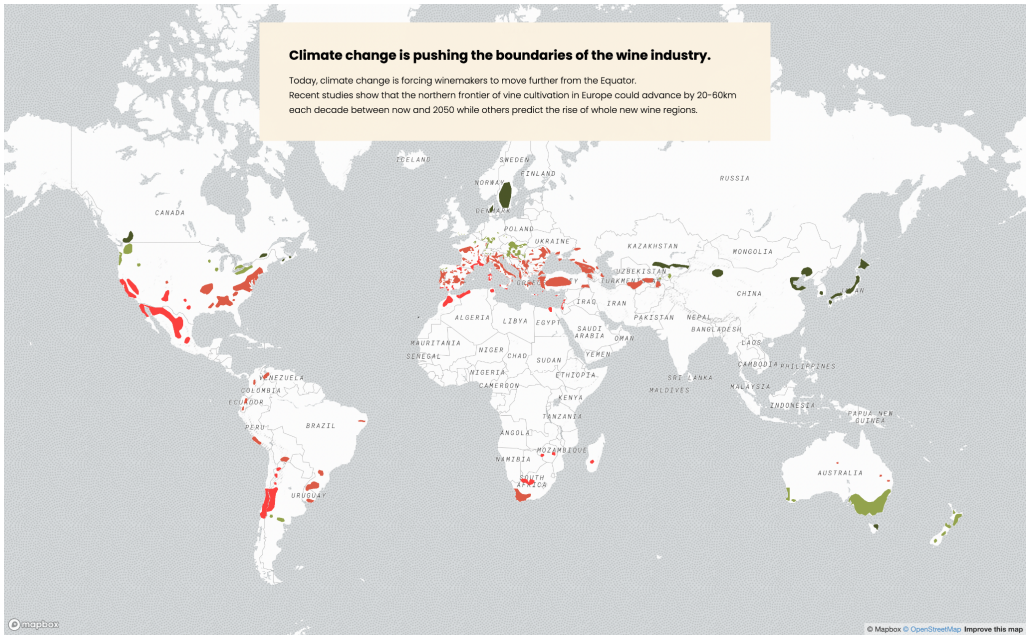
Other improvements concern gradually shifting the scrollytelling setup to a more exploratory interface. For example, to encourage the user to explore if his/her favorite wine is likely to be impacted by climate risks in the near future. The use of filters, zoom, search bars, time-based sliders (to dissociate different climate change scenarios for example) to better understand what is at stake with this project and encourage the user to dissociate “winning” wine regions from “losing” wine regions.

Aside from these further work directions, there were also some limitations in the current project that are worth noting. Depending on the target regions, the inconsistent availability of GIS datasets (to show how grape-growing areas are impacted by a given disaster) was a considerable obstacle since it prevented me from generating further case studies to illustrate other types of hazards (droughts, floods) that also tend to heavily impact wine regions.

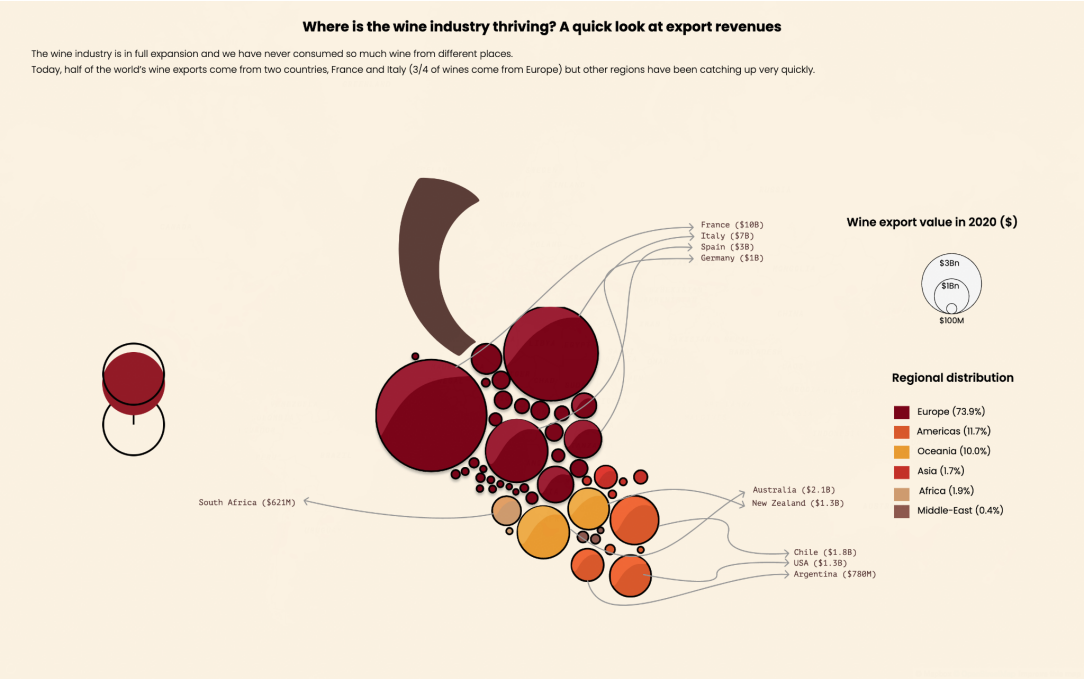
Finally, in closing this chapter, I hope this work proves useful and provides geospatial ideas as well as storytelling inspiration for other data visualization practitioners so that they continue making climate risk information as accessible as possible while searching for ways to better use existing the growing plethora of datasets.

Data Visualization Project & Datasets (May 2022)

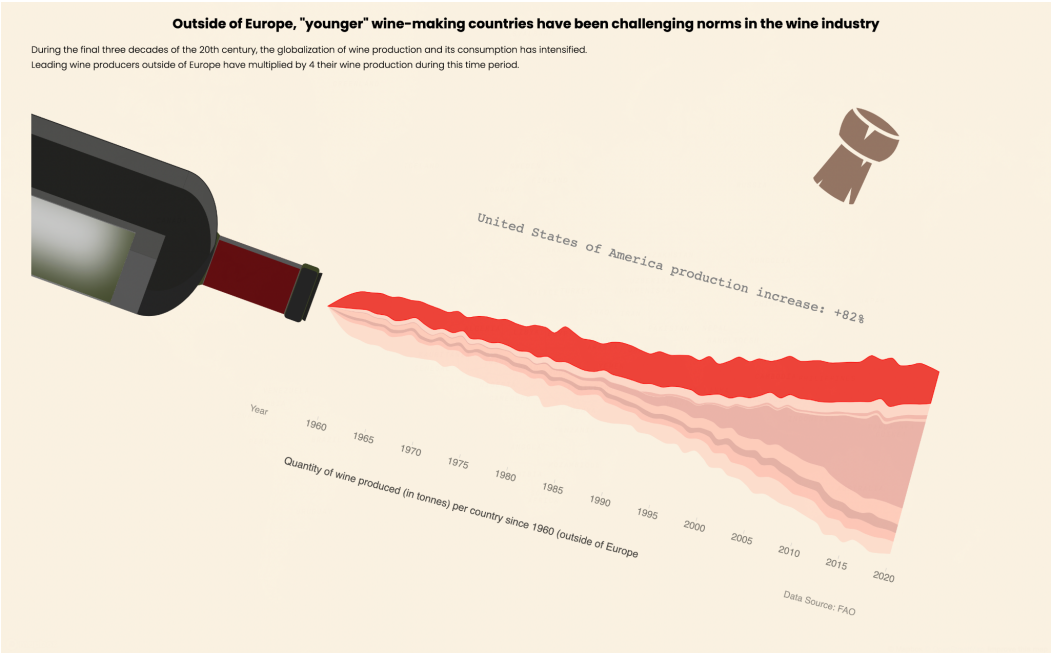
Landing page: opening video of data visualization project with title and subtitle
Video source: [Pexels]



First geovisualization displays the variety of wine regions around the world. Regions are color-coded based on their level of climate change exposure (red/dark orange colors for regions that will need to decrease or adapt, and green/light green colors for regions that will need to improve or emerge). Wine region classification provided by [Johnson-Bell, 2014].

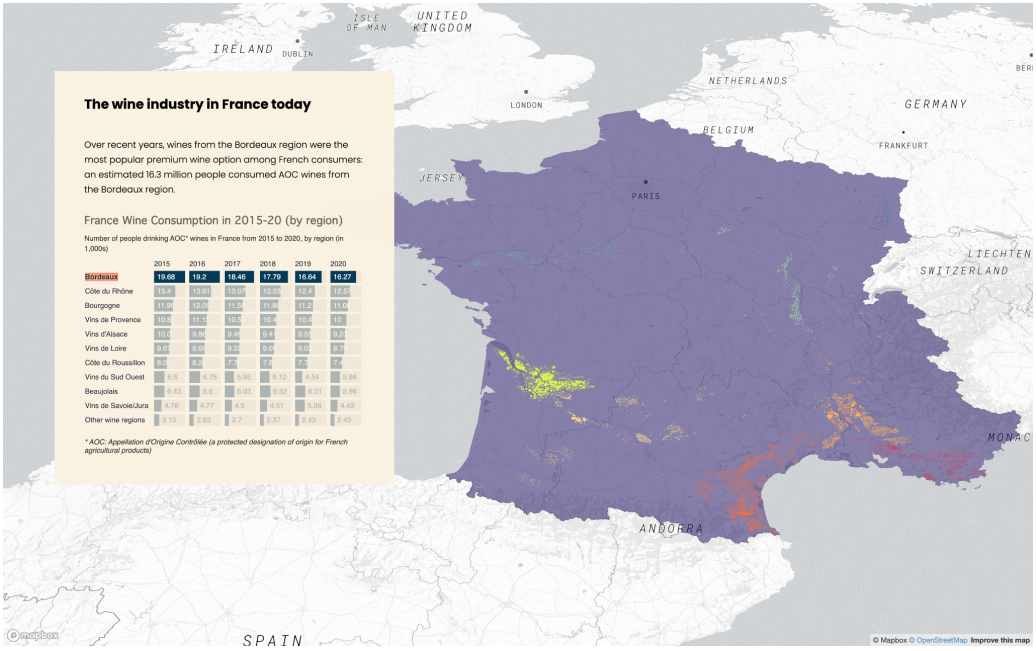


Circular packing (or circular treemap) - in the shape of a grape - breaks down which countries exported the most wine in 2020 and categorized countries based on regional affiliations. Each country's wine exports are represented by a circle with the dollar value which appears once the user hovers over it. The larger the circle, the greater the total value of that country's wine exports in 2020. Data for the visualization came from the International Trade Center. Only top-50 countries in the world's total wine exports are included in this visual.

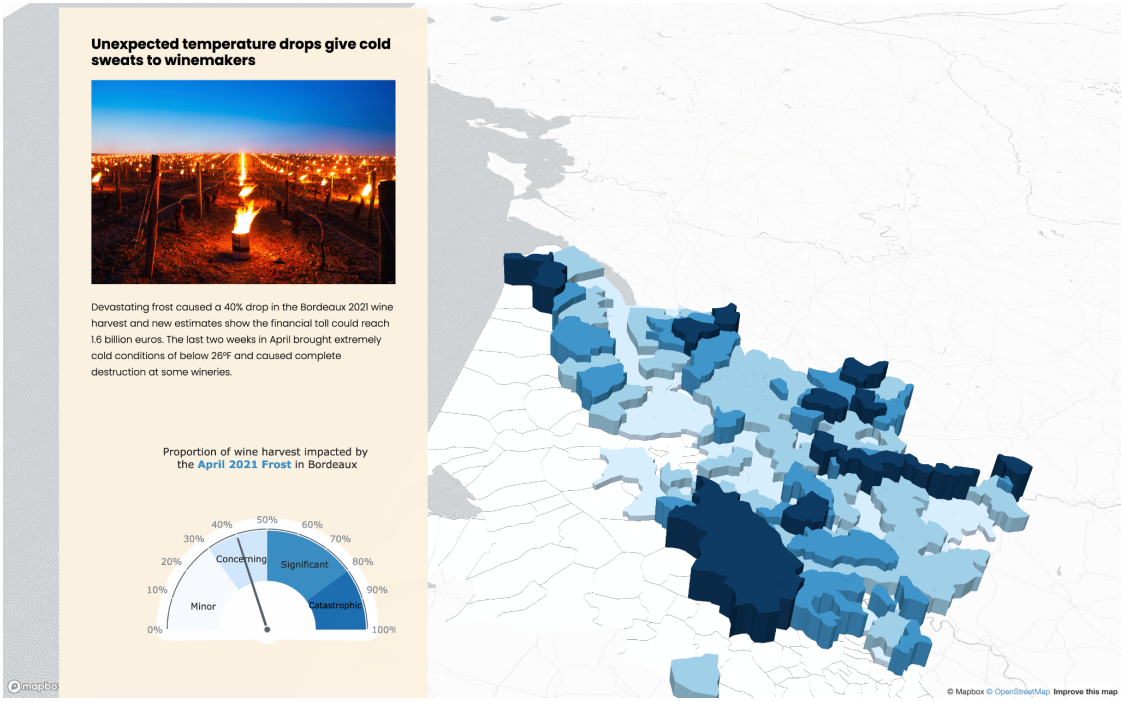


Animated stream chart displaying the quantity of wine produced (in tonnes) of non-European countries since 1960. Data is provided by the FAO. Only top-10 countries are represented.

Transition page to mark the beginning of the French "Chapter" (Bordeaux case study). Image: [Unsplash]

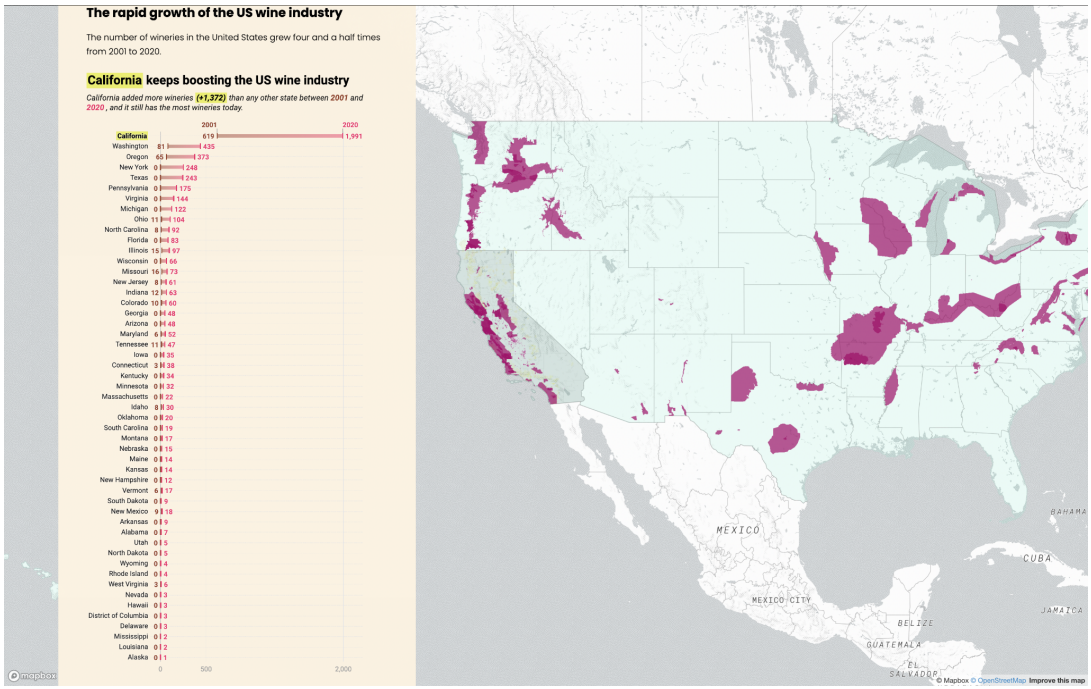


Map displaying the different AOC wine zones in France. AOC is short for Appellation d'Origine Contrôlée, and refers to standards set for wines made in France and control everything from how the grapes are grown to what wine varieties are in the bottle ([source]). In France, there is a governing body called the INAO (Institut National de l'Origine et de la Qualité, a branch of the French Ministry of Agriculture) which ensures quality for wine, cheese, and other food products. The INAO also manages the GIS datasets through its own dedicated [Open Data Portal].

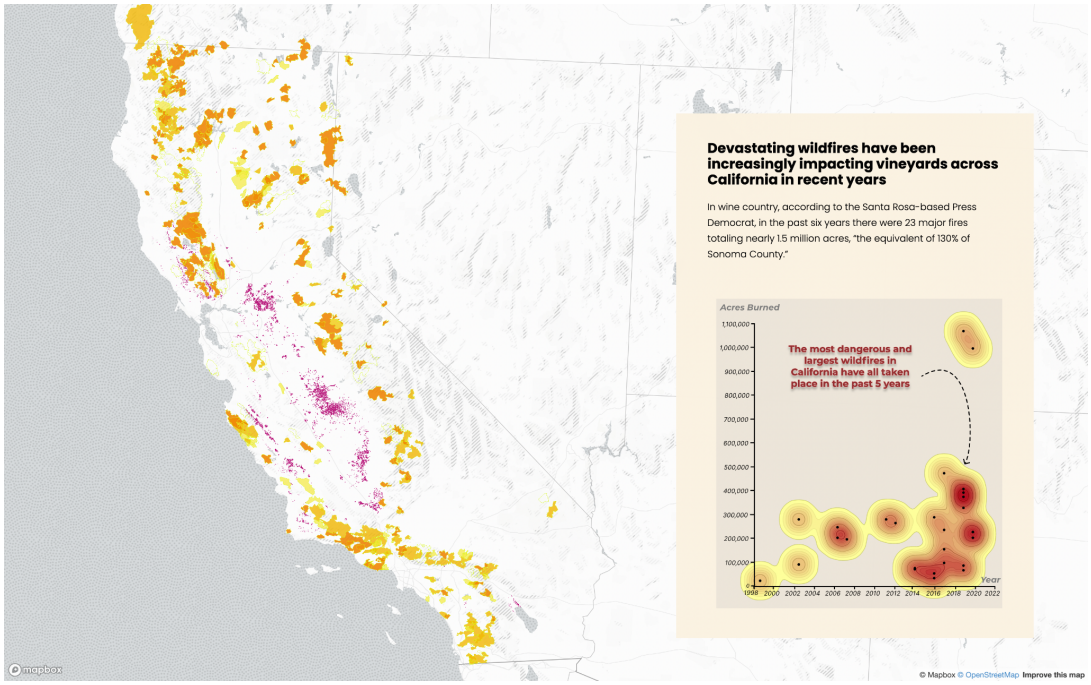


Map displaying frost damage level on a "commune" level (town) in Gironde (Bordeaux area) in April 2021. Frost damage data provided by the [Gironde Chamber of Agriculture](#).

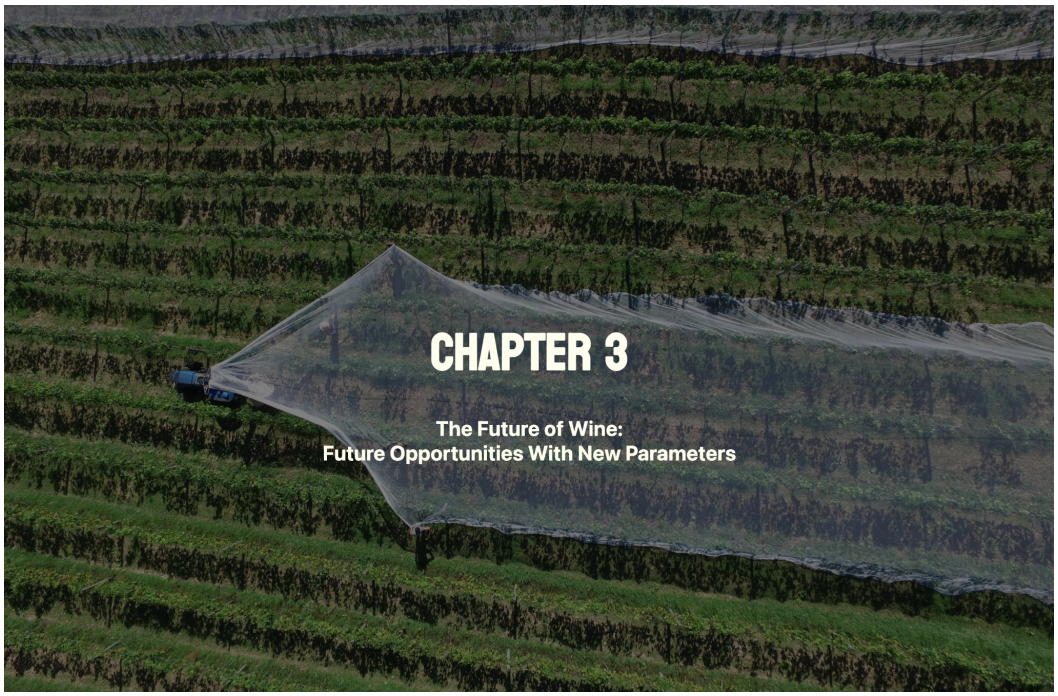
Transition page to mark the beginning of the US "Chapter" (California case study). Image: [Unsplash](#)



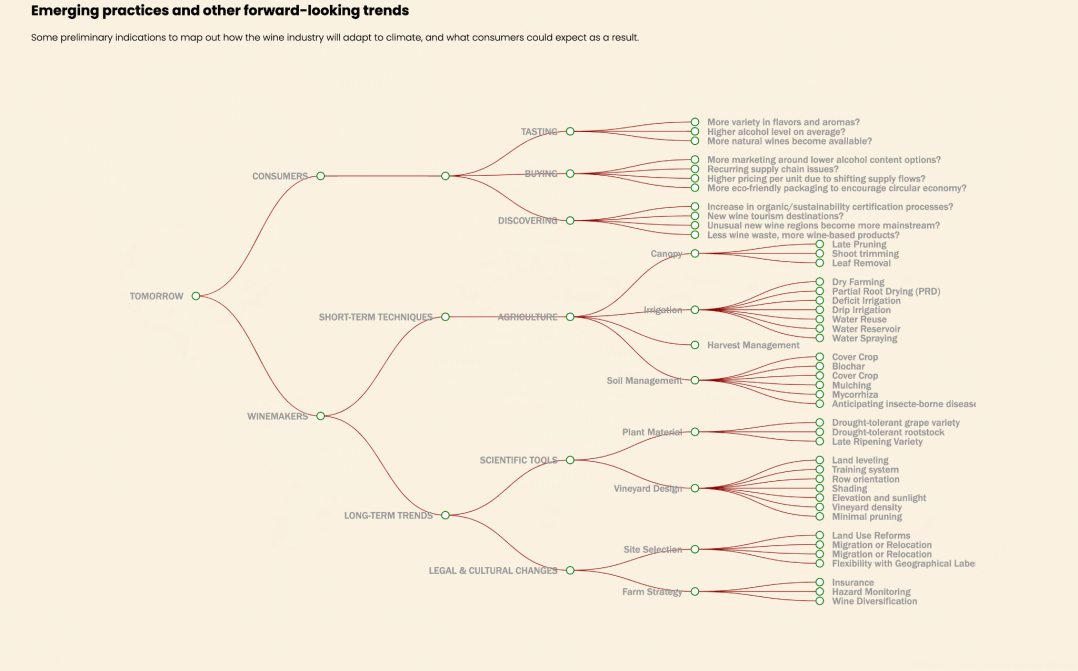
Map displaying the location of the existing AVAs (American Viticulture Areas). GIS dataset (shapefiles) provided and updated by the [American Viticulture Areas Digitizing Project]. The chart on the left hand side displays the growth in the number of wineries between 2001 and 2020 for every state. Wineries growth data provided by the [US Bureau of Labor Statistics].



Map displaying (1) burned areas between 2010 and 2019 and (2) current grape-growing areas across California. GIS shapefiles and fire data provided by [Cal Fire] (Burned Areas 2010-2020) and by [California US Department of Agriculture] (crop mapping of grape-growing areas).



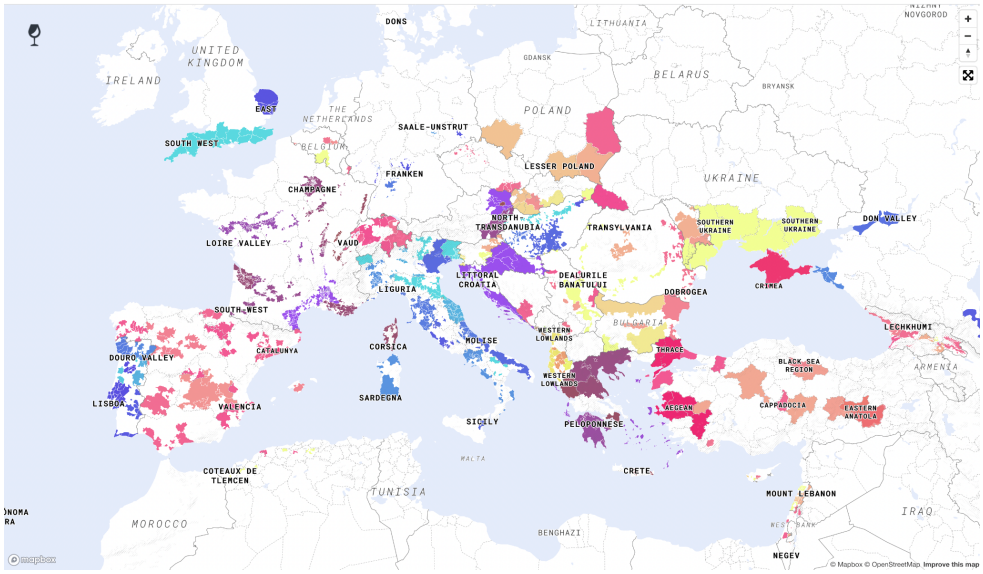
Transition page to mark the beginning of the Future of Wine "Chapter". Image: [Unsplash]



To end the data visualization project and to invite the reader to reflect on the future of the wine industry, a "layout tree" is used to display future trends consumers can expect, but also to flesh out potential measures being considered by winemakers to minimize the effects of climate change. Readers can click on nodes to close/open different branches and see how they are related to each other. Qualitative data is derived from a variety of secondary data reviews that was undertaken as part of the thesis research, and include media as well as academic sources.

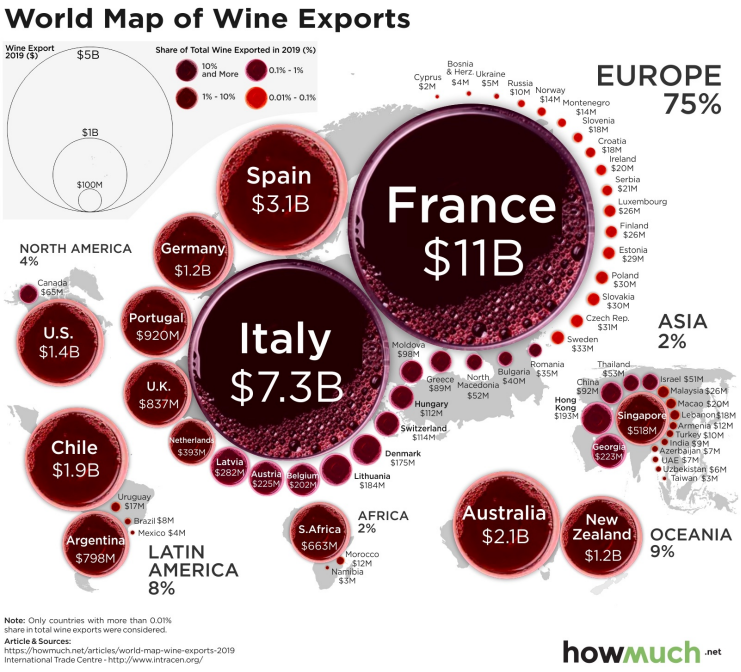
Appendix: Visual Inspiration

The following visuals were used for inspiration when several of the visual elements were being designed, prototyped and polished.

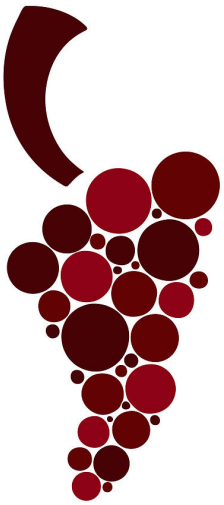


This wine map was used for styling several of the wine maps that were being designed.
Source: https://biarritz.io/map/

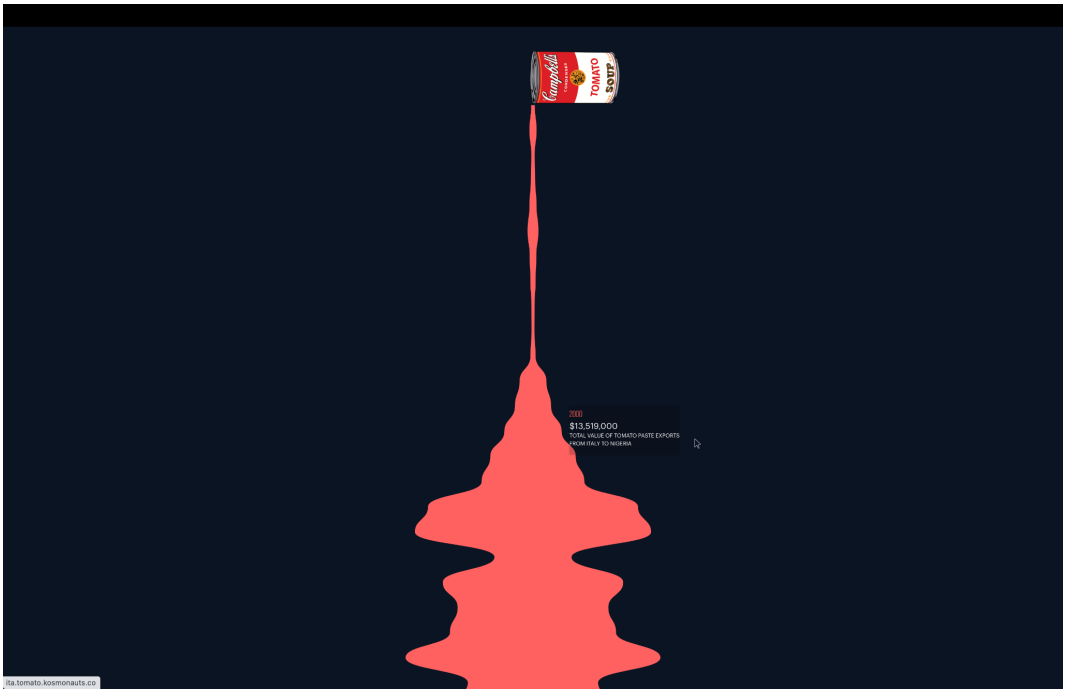
The following two visuals were used as inspirations for designing the circular packing (or circular treemap) that was in the shape of a grape which breaks down which countries exported the most wine in 2020 and categorized countries based on their regional affiliations.



Source: https://howmuch.net/articles/world-map-wine-exports-2019



Source: https://fineartamerica.com/featured/1-wine-grape-frank-tschakert.htm



This animated violin chart and the "flow" of time-driven data that came out of it was helpful in designing stream charts. Source: http://tomato.kosmonauts.co/

This illustration was used as inspiration for designing the animation and the content of the final GIF animation that appears on the very last slide. Source: https://www.davidebonazzi.com/news/the-new-york-times-the-problems-for-the-wine-industry

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