Viticulture in cold climate toward more sustainable wine production.

Vinodling i kallt klimat mot en mer hållbar vinproduktion.

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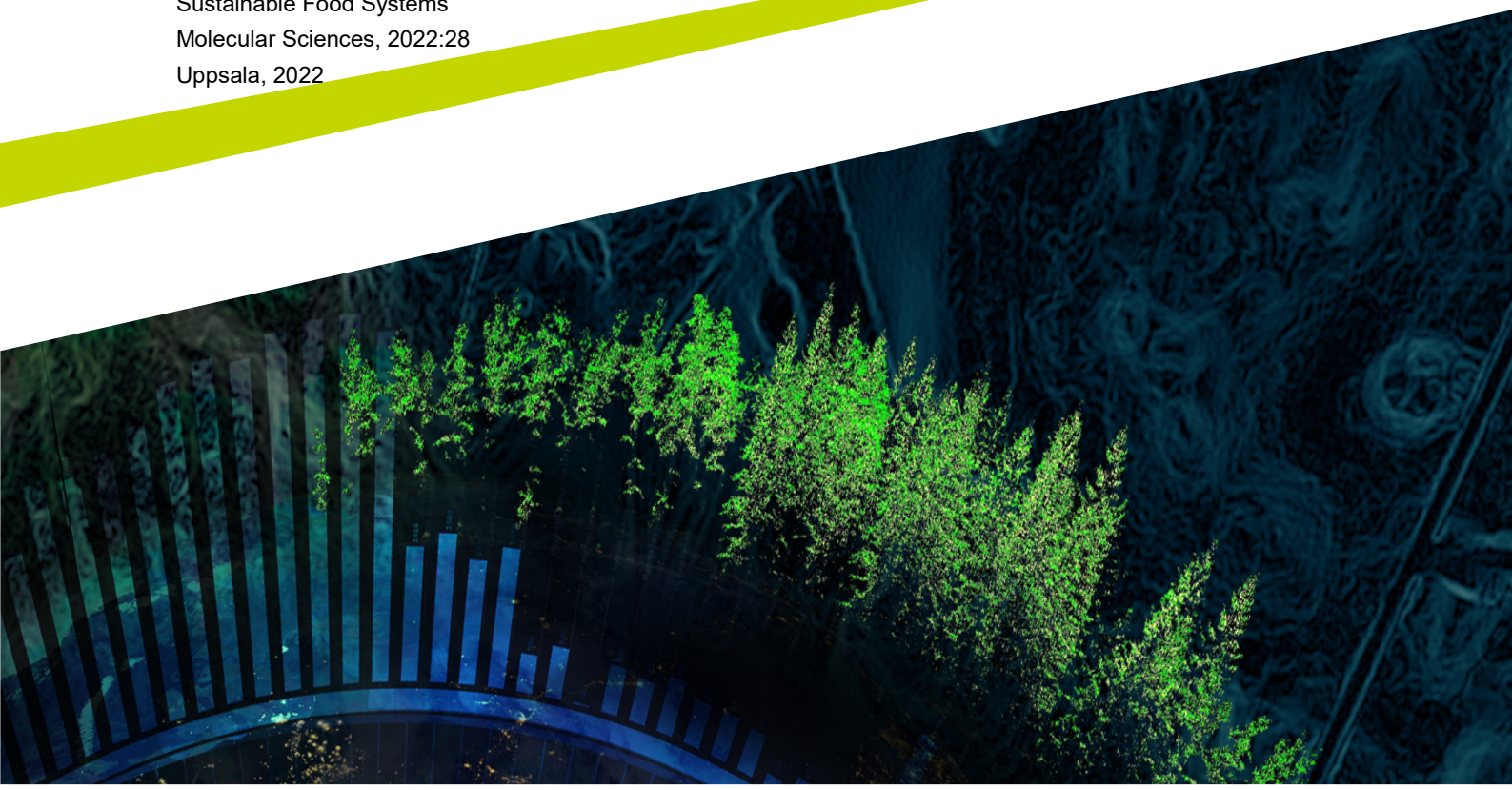

Viticulture in a cold climate toward more sustainable wine production – Vinodling i kallt klimat mot en mer hållbar vinproduktion

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Abstract:

This literature study investigates viticulture in a cold climate and how climate change could contribute to a more sustainable wine production. This study aims to investigate if wine production in cold climate regions could create a dynamic balance between productivity and the consumption of natural resources. The second aim is to identify the challenges and opportunities for a sustainable viticulture in cold climates concerning environmental, economic, and social dimensions. The results show that several factors affect viticulture productivity in cold climate countries such as climate factors (frost, high precipitation, short summer, temperature fluctuation), soil management, nutritional management, diseases, and production cost. Several sustainable challenges lead to environmental, social, and economic impacts. The use of fossil fuels, pesticides and chemical fertilizers can affect human health and the environment. There are good opportunities for building sustainable viticulture in a cold climate region by achieving the three dimensions of sustainability. In the environmental dimension practices such as site selection, an adaptation of new cultivars, mechanization, change of viticulture training system, good soil management, proper nutrition management, and the use of renewable energy should be applied. In the economic dimension improving energy and water efficiency (reducing cost), more sustainable training in agriculture and innovation, creating a new network in the supply chain to improve economies, and brand reputation are important. In the social dimension, cold climate viticulture would enhance local cooperation and communication, create local employment opportunities, promote healthy wine production that ensures respect for family standards, values, and beliefs, support local farmers, and promote worker health.

Keywords: **viticulture, cold climate, sustainable viticulture, viticulture and climate change, sustainable challenges, fungi resistance, SWOT, Terroir**

CONTENTS

Abbreviations:

LTI	Latitude and mean temperature of the warmest month indicator
SLU	Swedish University of Agricultural Sciences
V. vinifera	*Vitis vinifera*

1. Introduction:

Climate change affects both natural and human resources (Vermeulen et al. 2018). The term transformation with adaptation remains vague and has multiple definitions. These definitions vary in vision from relatively minor changes in crop locations to major redesigns of global food systems to meet societal goals for the environment, livelihoods, and nutrition (Vermeulen et al. 2018). Climate is critical when it comes to wine quality (Photiadou et al. 2017), as different weather fluctuations affect the content of grapes produced and hence the wine's properties. High temperatures and heavy rains caused by climate change are major challenges for viticulture management, these challenges create a new opportunity to transform viticulture into new cold regions (Photiadou et al. 2017). Grapes grown for wine production are grown on six of the seven continents(Jones & Schultz 2016), where the range and magnitude of environmental factors vary greatly from region to region as well as the main environmental constraints of grape production. Rising temperatures are often accompanied by increased heat stress and a change in the frequency of drought that is likely to challenge suitability and even viability. That being said, it has the potential to produce opportunities at the colder frontiers of wine production by expanding the appropriate areas(Jones & Schultz 2016). The vine belongs to the family *Vitaceae*, which is divided into different genera. At present, there are nineteen known genera that make up this family, including the genus *Vitis.* This genus, in turn, is divided into two subgenera: the subgenus *Muscadinia,* which today includes two species, and the subgenus *Vitis,* which includes more than eighty species originating from Asia, North America and Eurasia. *V. vinifera* species are divided into two subspecies: *V. vinifera* subsp *vinifera* and *V. vinifera* subsp *sylvestris*. *V. vinifera sylvestris* corresponds to wild vines, and *V. vinifera vinifera* corresponds to cultivated vines(De la Fuente Lloreda 2018). The vine (*Vitis vinifera*) is a grape used in wine production, and it has varieties suitable for cultivation at different temperatures range, which leads to variation in the yield and time of ripening, this leads to a difference in the quality and quantity of wine (Jones & Davis 2000). The cool climate for viticulture is

determined in regions where the temperatures for growth phase between April and October is between 13 and 15°C. Varieties adapted to this climate should be compatible with lower temperatures in summer and resistance to -18 ° C in winter. In spring the temperature should not drop to -1 ° C to avoid bud damage(Schultze & Sabbatini 2019). Sweden is located in the northern hemisphere between latitudes 55 and 70 degrees. There are specific areas in the southern part of Sweden where most of the high-value crops can be produced such as produced elsewhere in Europe(Nordmark et al. 2016). The climate in southern Sweden is usually warm with an average temperature of just under 0°C during February and the highest average summer temperature ranging from 15 to 17°C (July/August), with a vegetation period of 220 days. (Nordmark et al. 2016). In 1999, Sweden was approved as a wine country within the European Union, which can be considered recognition that Sweden is a wine-producing country(Lantbrukarnas Riksförbund 2018). There are more than 40 professional winegrowers in Sweden, most of them along the coasts of Skåne, but they are also starting to appear in other places such as Halland, Gotland, and Blekinge. In total, there are just over 100 hectares of commercial vineyards. Swedish vineyards are growing fast, and wine experts say they could reach 10,000 hectares within ten years(Bladini 2020). The nature of cold climate wines usually shows a balance between sugar, acid and alcohol content along with subtle fruity flavours(Gustafsson & Mårtensson 2005). Wine from cold climate conditions appears to have a higher quality, higher aroma, and delicate fruity bouquet, but may lack alcohol due to lower sugar content. At the cooler frontiers, it is only natural to find very high-quality white cultivars, in certain locations, because reds cultivars are more sensitive to cold weather conditions. It is not yet fully understood why colder climates have the potential to produce high-quality wine, but evidence suggests that the fluctuating temperatures of day and night in the fall are of particular importance. Cool autumn slows development, causes better balances of sugars and acids, and more flavor and aroma components accumulate, however, the quality of cold climate wines is variable because cold climates have the most common deviations from optimal conditions for fruit ripening. Since grapes sometimes have to be picked before they are fully ripe, the quality may suffer due to the too high content of malic acid and too low the sugar

content. There are major challenges facing the current production of viticulture, including the broader aspect of resource management in the production chain within the wine industry and the possibilities for its improvement (Schultz & Jones 2010).

1.1. Aim and Research Questions:

This thesis will focus on viticulture in a cold climate and how climate change could contribute to more sustainable wine production. This research will investigate if wine production in cold climates could create a dynamic balance between productivity and the consumption of natural resources to implement more sustainable wine production in cold and cool climate regions. The Research Questions are:

- What are the key factors that affect viticulture productivity in a cold climate and what are the possible climate impacts of the wine production chain?
- What are the current challenges and what are the possible improvements for achieving a more sustainable vine and wine production that satisfies environmental, social, and economic aspects in cold climate countries?

2. Methodology:

This is a literary study and research focusing on the scholarly literature including books and articles published and supported by the websites of private and governmental organizations. Database searches, and the use of internet search engines: Google Scholar, SLU Library, and Primo. A SWOT analysis will be applied to identify existing strengths, weaknesses, opportunities, and threats considered important to more sustainable viticulture in cold climates and the understanding of the adaptation of viticulture in cooler climates. The term “triple

bottom line" will also be applied to assess the economic, environmental, and social aspects of value creation for sustainable viticulture in cold climate regions.

3. Theoretical framework:

3.1. Definition of terroir concept in viticulture:

Terroir is a French word meaning "land" or "soil", which sums up the belief that every wine derives its properties from the environment in which the grapes are grown (Dougherty 2012. pp 50, 51). The concept of terroir is a belief that geography gives the wine a sense of place and makes it unique to wine production elsewhere. Terroir is thus a powerful geographical concept because it combines the spatial elements of the natural environment and its synthesis with socio-economic factors (Dougherty 2012. pp 50, 51). Vaudour (2002) identifies terroir as a system of complex interactions linking a specific physical environment with appropriate plant cultivation and appropriate winemaking. Terroir includes human aspects, in addition to the interaction between soil and climate. Hence it includes the various aspects of "nutriment", "space", "slogan" and "conscience". "Nutriment" or the soil in which plants grow refers to the technical and agricultural characteristics of the soil. It is based on a strong objective relationship that links the quality of wine with the characteristics of cultivation in the cultural environment. Good wine tasters are expected to be able to discern wines from various individual terrains. The "Space" refers to the part of the lands that have long been occupied, inhabited, and exploited, where a peasant community has settled and established the land, under the decrees on naming wine, the European viticultural lands are legally organized and meet the concept of territoriality. "Conscience" corresponds to different technological, social, and cultural meanings of a place or geographic origin that collectively refer to identity and memory. 'Slogan' is a term that powerfully recalls rural/ecological and communal values, therefore the association with the geographic origin of wine over time has become part of the concept of terroir (Vaudour 2002).

3.2. The triple bottom line:

The term "triple bottom line" is a new paradigm coined by John Elkington in 1994 that has three value underpinnings: the economic, environmental, and social aspects of value creation for sustainable conduct management. The triple bottom line offers different interpretations, prioritizing or making equal importance one of the foundations of value, emphasizing a common denominator, and considering these dimensions as conditions or outcomes(Belz & Peattie 2012). One might refer to the triple bottom line as a transition from an old paradigm to a new paradigm. Changes in values are associated with an increased understanding of problems, conditions, and outcomes. The value of taking responsibility would benefit a wide range of stakeholders. Concerning product function, from a cradle-to-grave perspective, life cycle or cradle-to-grave assessment is ultimately about increasing environmental efficiency while being economically viable(Mark-Herbert & Rotter 2010).

3.3. SWOT analysis:

A SWOT analysis is a useful tool for analyzing the internal and external environment around a business(Valentin 2001). The internal environment consists of strengths and weaknesses. The external environment consists of opportunities and threats. There is no doubt that SWOT analysis is a valuable tool in the field of business strategy because it invites decision-makers to consider important aspects of their organization's environment and helps them organize their ideas(Valentin 2001). But the open nature and unstructured manner of SWOT offers little help to users and planners who are left without an indication of where to look for such variables, or what to do after finding them among the best ways to incorporate them into strategy formulation. Suggestions from researchers for developing various modified frameworks to focus on SWOT to improve its results and enhance the planning process(Panagiotou 2003).

4. Results:

To answer the research questions, a literature review was conducted to list the main answers for the adoption of viticulture in cold climates. Research papers were browsed to identify the key factors affecting viticulture productivity in cold climates considering the complexity of assessing sustainable dimensions. Threats and opportunities to achieve more sustainable wine production in cold climates have been identified.

4.1. Literature review

4.1.1. Factors affecting viticulture productivity in cold climate countries

Weather and nutritional management:

In the northern and northeastern United States, grapevines experience harsh, cold winters and warm, humid summers (Londo & Martinson 2016). As a result, the primary limiting factor to producing vineyards of *vinifera* cultivars in the North and Northeast US is low winter temperatures. As a perennial fruit crop, grapes defend their tissues against winter damage through the processes of dormancy and acclimation. These processes are influenced by climatic features that remain constant such as decreasing day length in autumn and winter, and by features that vary from year to year, such as temperature fluctuations. In addition, each grape variety (such as *Riesling, Merlot, Concord*) contains a unique set of genes that allow this variety to respond to surrounding environmental conditions. Different grape varieties differ in the depth of response to cold temperatures and the speed with which they respond (Londo & Martinson 2016). The LTI uses the latitude and mean temperature of the warmest month as a proxy indicator for solar energy that regions are likely to receive during the growing season, but latitude is not the only factor that determines growing conditions. Restrictive climatic conditions can be

combated by growing grape varieties that are adapted to ripening under cool conditions and/or during short seasons, through appropriate training and vine pruning that maximizes the use of sunlight and heat available for ripening. Also, adopting measures to improve plant protection in cold winters may make successful viticulture possible under the prevailing cold climatic conditions (Gustafsson & Mårtensson 2005). Cold hardiness is a term used to describe the complex winter survival mechanisms of plants. Grapevine winter survival is a multi-stage process that begins in the fall as day length shortens and temperature drops. Grapes begin the process of acclimatization with the gradual ripening of the cane from green to brown surrounding the dermis. During this period, the grapevine goes from active growth with light-green leaves to a dormant phase, where it gradually becomes more resistant to cold temperatures (Londo & Martinson 2016).

A study conducted in Australia shows that Australian wine companies have largely failed to invest adequately in truly cold-climate viticulture regions such as Tasmania and continue to lose market share in the domestic market to New Zealand (Doyle 2014). Tasmania has the resources to significantly increase wine production, and this can contribute to Tasmania's economy in general, particularly at the regional level. The climate of Tasmania can be described as covering a range of cold to very cold conditions and areas of heavy rainfall. Only a small percentage of Tasmania's land area is realistically available for vineyard development, due to competition for land use, from forest reserves, plantations, and other forms of agriculture, especially grazing and cropping. There are 20 vineyard areas, with higher precipitation, where the risk of fungal diseases will increase. Areas with lower rainfall will need higher amounts of irrigation. Regions with lower temperature values for degree days may have a better chance of producing higher quality *Pinot Noir* and other table wines, sparkling wines. Rainfall in Tasmania is generally liberal although irrigation is required on most vineyards as a necessary supplement (Doyle 2014). There is a great variance in yield among the vineyards, the large seasonal variation was due to prolonged flowering in cold and wet weather affecting fruit set and consequently the bunch weight at harvest, because of large numbers of small, unfertilized berries at harvest which caused low bunch weight.

Very cold regions of Tasmania will have greater risks associated with late harvest and more bunch rot, due to insufficient ripening. Frost damage can destroy the production of the vineyard because flowers and leaves can be damaged, and that will reduce the yield in the current season. When frosts are particularly severe, another problem for cane pruned vines is shoot death, which can lead to a lack of suitable canes for the subsequent season's crop, so one frost event may damage production for two seasons (Doyle 2014). Frost damage can be avoided in two ways choosing locations with negligible risk of frost damage or installing frost protection systems such as wind machines or overhead sprinklers. Frost analysis is critical before any vineyard development. Cultivation too low in the landscape may represent a significant cost if frost protection is not included in the development. In Tasmania, there is a relationship between variables as diverse as yield, vigour, canopy traits, fruit, and wine composition, and vineyard climate, especially air temperature (Doyle 2014).

In November 2020, temperatures in Sweden exceeded 18 degrees in southern Sweden(Bladini 2020). This means that the opportunity to grow wine becomes greater, the season becomes longer, and many types of grapes can thrive. Another factor contributing to the possibility of wine growing in Sweden is the new grape varieties that were developed at the end of the 20th century. Developed for a cooler climate, the grapes are cold tolerant and easier to ripen than traditional grape varieties(Bladini 2020). *Piwi* vines are crosses between *Vitis* genera, whereby the outstanding characteristics, resilience, and qualities are combined. *Piwi* vines have a high resistance to fungal diseases and allow a significant reduction in the use of pesticides, thus protecting the environment(PIWI sustainable 2022). Today the *Piwi* grape is the most widely cultivated grape variety in Scandinavia and examples of the cultivars are *Solaris, Souvignier gris, Muscaris,* and *Cabernet Cortis*(Bladini 2020). Green *Solaris* grapes have proven to work best in Swedish viticulture and are also the most popular. The *Solaris* grape is the result of a program focused on developing disease-resistant grape varieties, which have good resistance to fungal attack. It is a very winter-hardy grape variety and therefore well suited when growing grapes.(Henriksdals vingård 2019).

Farmers' interventions are a critical method aimed at more appropriate nutritional management. The most balanced and productive vines have good nutrient absorption and avoid nutritional deficiencies, ensuring high quality. It becomes very important to control the nutritional status of the resistant cultivars, through leaf analysis, calibration of specific interventions annually, and concerning a different type of soil (Porro et al. 2022). Some nutrients may act as a tool to overcome stresses caused by cold climatic conditions; balanced supplements are essential, and unbalanced fertilization may reduce plant vitality (Gustafsson & Mårtensson 2005). Nitrogen is the plant nutrient that has the greatest effect on the vegetative growth of the vine. The nitrogen requirements of young grape plants must be met to ensure their strong vegetative growth. Once it is time to start harvesting grapes from the vineyards, N fertilization should be restricted because excessive vegetative growth impairs yields both quantitatively and qualitatively. When N is in abundance, plant cells rapidly develop and become water-logged and diffuse, making a plant vulnerable to temperature fluctuations.

Stimulation of vegetative growth by N. fertilization reduces the winter viability of the vine, which leads to an increased risk of winter damage. Phosphorous is the phytonutrient most associated with improved winter hardiness in cultivated plants. So good access to P would increase winter hardiness in vines. Vines have a relatively high potassium requirement since a large amount is removed with the harvested crop. Although K is generally not associated with winter hardiness in cultivated plants, balanced K fertilization can improve plant health and thus increases the ability to resist the stress of the winter period. Boron is the most important micronutrient for grapevines, with both too high and too low harmful concentrations of boron. However, boron has no documented effect on winter hardiness (Gustafsson & Mårtensson 2005). The good presence of mineral elements in the leaves reflects the optimal absorption of plants from the soil, for example, Solaris should be monitored for N, and specific control of Mn levels should be determined above all when cold and wet spring occurs (Porro et al. 2022).

Soil management:

Soil management has a significant impact on vine yield and quality (Gustafsson & Mårtensson 2005). Cover crops are among the most attractive options for soil management in vineyards(Abad et al. 2021), as they increase soil organic carbon, improve water intrusion and aggregate stability, reduce soil erosion and greenhouse gas emissions, and increase vineyard biodiversity. Cover crops tend to result in reduced vegetative growth of vineyards, which can usually be associated with a lower incidence of major fungal diseases. Cover crops generally reduce the incidence of pests, especially *cycadilida* and mite species, the presence of which increases natural enemies. In general, cover crops increase the water deficit, although this effect is highly variable as it depends on the characteristics of the soil and climate, and on the period of the year in which the covers are active. The increased competition for water that occurs when using cover crops can be modified, to some extent, by the fact that cover crops increase water intrusion into the soil and may reduce soil evaporation(Abad et al. 2021). A cover crop can contribute to nitrogen fertilization and improve potassium availability.

It is also possible to use a covering material that can be of organic or inorganic origin, and the choice of materials with light or dark colors affects the absorption/reflection of heat. Mulching in the winter reduces the risk of killing in the winter but increases the risk of rat and mice attacks. Mulch with shingles is an interesting alternative because the soil absorbs and releases heat during the night, reducing the risk of frost damage during flowering. In addition, covering that are less prone to rodent attacks such as organic materials or plastic can also be used. Grapes are sensitive to a lack of oxygen. Perfect drainage is critical to successful viticulture. Wet soil reduces oxygen in the root zone and prevents the roots from absorbing water. (Gustafsson & Mårtensson 2005). However, as vines and cover crops coexist in the same space, they compete for nutrients and water at certain moments of the season, which may directly affect the performance of the vineyards. The severity of these effects depends largely on many factors, such as characteristics of crop cover, soil type, climate, and other characteristics of vineyards (Abad et al. 2021). An alternative to soil cover is straw, which is excellent if it does not get wet. Using foam panels, geo-textiles, and snow fences are effective

methods of winter protection. In the absence of snow, the soil cover will freeze deeply and may injure the roots of the vine so natural or artificial snow cover is an alternative to protect the vines. Artificial snow is more efficient than natural snow as cover because the melt holes that arise along vine shoots are smaller with artificial snow than with natural snow (Gustafsson & Mårtensson 2005).

Diseases

In the cold climate grape-growing world, various parts suffer from different diseases and pests. Some diseases and pests can cause problems in cold regions (Gustafsson & Mårtensson 2005). *Phylloxera (Daktylospahira vitifoliae)* is a small insect that entered Europe from America, Phylloxera weakens plants primarily by feeding on their roots and usually causes the vines to die in 3 to 10 years. In areas where infestation reaches the economic limit of damage, the only successful method to eradicate the insect is to remove the vines, burn them, treat the soil, and replant *Vitis vinifera* grafted onto the tolerant rootstocks. *Downy mildew* (*Plasmopara viticola*) (Gustafsson & Mårtensson 2005) is common in wet weather and attacks the leaves but does not generally affect the ripening of the fruits. *Gray mold* is the most dangerous type of *mold* in wet weather; It attacks ripe fruits and may harm the harvest.

Fungi such as *Aspergillus* and *Cladosporium* in contrast to *Botrytis* cause the berries to have a pungent, vinegary smell. They tend to attack berries that are already physically damaged in heavy soils, especially in wet seasons. Rot and viruses are not specifically associated with cold climatic conditions. (Gustafsson & Mårtensson 2005). In Northeast Italy where viticulture areas have high annual rainfall, many applications of fungicides are required. Thus, the possibility of using resistant varieties is a real choice for grape producers(Porro et al. 2022). For example using *Piwi* varieties which have a high resistance to fungal diseases and allow a significant reduction in the use of pesticides (PIWI sustainable 2022).

Production cost

The wine sector in general suffers from insufficient economic sustainability. Profitability is particularly low for wholesale wine producers, who have to act as price catchers in the increasingly globalized wholesale wine market (Strub et al.

2021). In Germany, production cost and production volume are the main drivers of profits for wholesale wine producers. Wholesale wine producers cannot differentiate themselves by building an image and adding brand value, and they rarely benefit from higher product quality (Strub et al. 2021). Viticulture costs have been significantly reduced through mechanization. However, on flatlands, it is unlikely that there is potential for further mechanization and cost reduction of conventional viticulture systems. Severely inclined wine producers suffer from the cost disadvantages of viticulture. New developments in viticulture mechanization, such as steep slope harvesters, rope, and winch systems, can partially reduce viticulture costs (Strub et al. 2021). The total cost of mechanized viticulture on steep slope sites is still higher than on flat terrain sites. Any option that compensates for these cost disadvantages can contribute to the sustainability and conservation of viticulture on steep slopes. Low-input training systems allow for full mechanization of viticulture operations (i.e., pruning), thus greatly reducing the labour demand for viticulture pruning and winter canopy management. Low-input trained sites generally result in higher yields that reduce the cost per liter of wine. This is the second factor of cost-saving besides the generally low absolute cost of growing viticulture for low-input trained sites (Strub et al. 2021). The advantage of higher yield and the lower total cost is of particular importance for market entry for mid-level producers, as well as wholesale wine producers who account for a large share of the wine market. If any or all producers switch to low-input training and produce higher returns at lower cost, aggregate market prices will fall. This will increase the global supply of wine. Ultimately, production costs are lower in sites of warm, flat terrain that can be more easily irrigated and for which low-input training is appropriate, enhancing their advantage in terms of the cost-efficiency of viticulture. Producers can only temporarily benefit from innovations such as low-input training systems, through their wider adoption. Climate change could favour or penalize the widespread adoption of low-input training regimens. Due to its potential to delay maturation, low-input training has been identified as a possible strategy to reduce the speed of climate change-induced maturation processes (Strub et al. 2021).

4.1.2. Sustainable viticulture threats and opportunities in cold climate countries:

Canada case study:

Ontario is a cold climate growing area, like northern France and Germany, and Canada's largest province wine producer, responsible for nearly half of Canada's total economic impact of wine. It is the world's largest producer and exporter of iced wine, but the wine industry there is considered nascent (Tasic 2019). The challenge many winemakers face with growing grapes in Ontario is that harsh winters damage soft vines and soft fruit clusters, which can negatively affect both the yield and quality of grape wine, and conversely, Ontario's humid summers invite fungi and pests' diseases. Hotter summers, warmer winters, and longer growing seasons make many wineries need to change their views to view climate change as a long-term, ongoing condition. Taking actions to achieve the 2030 Sustainable Development Goals, sustainable agriculture is a new concept. While the research to back it up exists, there are not ample practical presentations on how to transform industrial agricultural practices into more sustainable practices (Tasic 2019).

New Zealand case study:

In New Zealand the wine industry is also vulnerable and sensitive to geological as well as climatic, market, and biological pressures(Cradock-Henry & Fountain 2019). These have negative effects on wine producers and grape farmers' profitability. Promoting resilience is one way for the industry to better absorb the effects of disruptive events and reduce negative impacts. The basis of resilience theory is that social and ecological (socio-environmental) systems are intrinsically linked and experience constant change, the outcomes of which are inherently unpredictable. For example, Cradock-Henry and Fountain (2019) used a resilience-based approach to assess the effects of the 2016 earthquake. The earthquake affected infrastructure, which had implications for production, yields, and therefore income. The extensive ground movement has particularly damaged processing and storage facilities. The most important direct influence on the wine industry was storage capacity. Privately owned wineries were able to mitigate the immediate

effects by moving capacity elsewhere or writing off the losses. Wineries were more likely to bring in temporary storage or to access storage capacity in other areas (Cradock-Henry & Fountain 2019).

UK case study:

In the UK, the minimum, average and maximum temperatures increased in all seasons across the country, and annual atmospheric frost frequencies decreased(Nesbitt et al. 2016). A study showed that dominant grape cultivars have changed due to climate variability. Under a scenario in which greenhouse gas emissions continue to rise, high variability in temperature and precipitation in the southeast and the south-central UK, and in England and Wales, and changing growing season between years poses a threat to productivity. On a monthly scale, rainfall in the southeast and the south-central UK during June has been shown to have a statistically significant relationship with yield, regardless of changes in thermal averages and the dispersal of June precipitation volume is a constant threat to flowering and fruit set(Nesbitt et al. 2016). Hence farmers/producers have attributed low yield to changes in precipitation patterns. The spring months of April and May have seen large increases in temperature which affect the plant since this is the time when bud growth and initial bud growth occur. A warmer temperature currently indicates that the growing season for grapes is progressing and prolonging. When warmer temperatures occur in April, weather frost events in May are likely to cause more damage. The dangers of spring air frost, wet flowering conditions, and fruit sets remain a serious and sustainable threat. Harvest-period conditions in the southeast and the south-central UK are becoming much warmer and wetter, increasing the potential for increased disease stress at this time. Climatic risks in viticulture can be mitigated by management strategies, market forces, and their ability to handle years of low yields(Nesbitt et al. 2016).

US case studies:

In the US, a study was applied to four cold-climate viticulture regions in the United States: two in Michigan, one in upstate New York, and one in Oregon. The warming trend in cold-climate viticulture could allow the introduction of

alternative grape varieties, greatly improving the limited availability of cold-climate *Vitis vinifera* cultivars(Schultze & Sabbatini 2019) . In cold-climate viticulture regions of the United States, seasonal variation may remain high, but adding significantly warmer growing seasons will ensure that these regions do not need to compete with years of exceptionally cold winters, or cool summers that can limit production. Precipitation trends are also a concern at all sites in this study. Such events can cause erosion and can be associated with severe weather that may damage the vines or their fruit. In general, seasonal trends in precipitation are mixed. Increased January and February precipitation at the Michigan and Finger Lakes sites indicates that winter precipitation will still be available to protect the vines in the cooler months. However, increased rainfall in September and October in the Michigan and Corvallis regions can be a problem. A change in precipitation patterns can exacerbate the problem of physiological ripening of the fruit, increasing the potential for a complex cluster rot problem at harvest. In these cold regions, shifts in climate will lead to shifts in phenology, and warming is likely to benefit the cultivation of a wide range of cultivars (Schultze & Sabbatini 2019).

Another study conducted in cold regions of the eastern and western-central United States showed that the development of cold acclimatization of the plant goes from the bottom up and the less vigorous vegetative growth may be one reason for better acclimatization to cold. Vigorous growth during the fall prevents acclimatization to cold before frost. So high-strength sticks are less cold-hardy than less strong sticks (Zabadal et al. 2007). Winter infestation of vineyards is a challenge for grape growers Preventing vine infestation is a major concern in viticulture in many grape regions, especially cold-pressed *Vitis vinifera* cultivars, and has many adverse effects on wine growing in cold regions of the eastern and western-central United States. Winter injury is also the main cause of disease development in vines. Infected or dead canes, stems, and shoots cause crop losses or, the need to replant the vines with the concomitant large loss of production and income. These losses to winter injuries can be devastating to the vineyard business and may affect the profitability of the vineyard for many years. There is also an emotional cost to the farms, especially to new grape growers who may

expect their first crop, only to see the vines die before they can become productive (Zabadal et al. 2007). Practices such as using wind machines to mix cold and warm air to reduce the severity of winter injury in vines and careful site selection may be the most important decision a new grower can make. The risks inherent in growing in cold conditions require that farmers consider the impact of crop loss on their business and ask themselves how they can manage this risk. Two ways farmers and wineries can reduce risk is by diversifying the mix of varieties and using crop insurance to protect against catastrophic losses. Maintaining the number of vines is one of the most crucial factors that determine the profitability of a vineyard. (Zabadal et al. 2007).

4.1.3. Sustainable dimensions and wine production in cold climate countries:

Canada case study:

There is significant marketing value to sustainable wine, as it could be argued that sustainability has an emotional resonance for consumers. There are opportunities to be considered for implementing more sustainable wine production on the economic, social, and environmental dimensions(Tasic 2019). On the economic front, a study conducted in Canada argued that with the cultivation of a new grape variety, wine could be priced at a higher price range which would increase profitability. In the social aspect, increased wine education and programming are steps towards directing future generations to more sustainable practices such as creating jobs, year-round tourism, and enhancing the livelihoods of residents. In the environmental dimension, some farmers return to the biodynamic farming method that preserves the bio environment, thus reducing the pollution caused by agriculture and increasing biodiversity(Tasic 2019). Wine companies are vulnerable to the effects of weather and, less to economic downturns (Draayer & Julien 2010). For example, “Grapeview” is a wine company in Canada that does not expect to see a drop in sales. To keep up the competition, "Grapeview" has undertaken several major activities: they have tried to stay in the public eye by sending their wines to wine writers to publish positive articles about them in

respected wine magazines. They have been committed to meeting quality and production standards to stay ahead of their competitors. They also participated in many trade fairs, participated in many tour groups, and participated in Ice Wine Festivals to gain more exposure. Some wineries offer a standard set of benefits to employed staff such as medical and dental insurance, travel reimbursement for wine conferences, and professional development (Draayer & Julien 2010).

Bulgaria case study:

Geographically, Bulgaria has the natural climatic conditions to develop the wine sector into a progressive and profitable industry, but political support is needed to counteract the threats(Petkova 2011). Quality objectives are related to the overall performance of Bulgarian wine, as well as directed to its fans. Hence the supply of high-quality raw materials and improved technology is a decisive factor in competitive wine production. Providing high-quality education, opportunities for practical training, practical research, international technology, and the exchange of specialists are critical. Compliance of safety standards with the requirements of European and global consumers for high standards and consistency of quality, safety, and health food effects are also crucial when it comes to wine production in Bulgaria. This study also showed that to build or defend the image of Bulgarian wine, the consumer needs to know and remember its attractiveness, so active marketing is an essential point of protecting intellectual property rights. Increasing the share of high-quality wine by modernizing technology is a great way to develop wine production. There is also an economic potential in combining natural and historical features in viticulture and wine production. The final product must contain cultural heritage, natural and regional features, local characteristics, customs, and traditions(Petkova 2011).

France (Loire Valley) case study:

Viticulture is a large consumer of fuel and emissions from its consumption have many impacts on the environment (global warming, acidification, photochemical ozone formation)(Rouault et al. 2016). Plant protection and soil management treatments are the processes that have the greatest impact. The main reason for these effects is the combustion of fuel while tractors are working in the vineyard.

The demand for fossil resources is directly related to fuel consumption as only petroleum extraction is considered(Rouault et al. 2016). Global warming correlates with greenhouse gas emissions from fuel combustion. Similarly, acidification correlates with emissions of nitrogen oxides from fuel combustion. Thus, reducing the impact would require reduced fuel consumption or adoption of eco-driving or electric tractors. The second major effect of viticulture is the emissions of nitrates into the water, which contribute to eutrophication(Rouault et al. 2016). The risk of eutrophication in viticulture production is mostly due to emissions of nitrates which are associated with the washing out of soil nitrogen through precipitation. Reducing fertilizer use should reduce nitrate emissions and thus increase nutrients. Emissions of heavy metals are the main sources of environmental toxicity for freshwater, and are closely related to erosion and leaching(Rouault et al. 2016).

US case study:

A third study conducted in the United States of America to evaluated the methodology for developing a wine rating system for the sustainable attribute of a bottle of wine (Valero et al. 2019). The ten medium-point impact categories evaluated were “ozone depletion,” “global warming,” “smog,” “acidification,” eutrophication”, “carcinogenicity”, “non-carcinogenic”, “respiratory effects”, “environmental toxicity” and “fossil fuel depletion”. Based on Life Cycle Assessment (LCA), grape growing is the process that contributes the most to the ecotoxic, non-carcinogenic, and nutritional impact categories, while the transport phases contribute the most to global warming, smog, and layer depletion. Ozone is affected when the bottles are made in China. The impact of ozone depletion is four times greater for the supply chain as the grapes need to be transported in a refrigerator (Valero et al. 2019).

Italy case study:

There is no recognized definition of sustainability in wineries, nor a common framework for implementing sustainable practices(Moggi et al. 2020). Environmentally friendly practices contribute to better quality grapes that are healthier with fewer chemical fertilizers and improved worker health. There is an

interest in improving the environmental efficiency of operations considering the circular economy and its potential for waste recycling as a source of heating. In this sense, the level of development is diverse and includes wineries that boost efficiency towards sustainability from vineyard to bottle. Water use is also seen as a growing concern, with water being used in a more precise and accurate manner(Moggi et al. 2020). To improve sustainability in viticulture actions should be implemented on the three dimensions (Table 1).

Table1: Viticulture and sustainability dimensions

Sustainability dimensions	Environmental	Economic	Social
Actions	-Water Consumption Management (Appropriate Irrigation Systems) -Good soil management (crop cover, chemical pesticides, and less fertilizers.) -Promote biodiversity. waste management -Use renewable energy. Eco-friendly packaging	-Improving energy and water efficiency (reducing cost). -EU funds for sustainable agriculture and innovation -Increase sales margins and sales value -Creating Shared Value -A new network in the supply chain to improve economies of scale -Brand reputation and identity	-landscape restoration -Local collaboration and communication -Create local job opportunities -Health and safety plans -Sustainability Training -Family norms, values, and beliefs - Support local farmers.

Source: inspired by (Moggi et al. 2020)

By comparing the three dimensions of sustainability, in the environmental dimension, water issues were emphasized as a priority for wineries that have faced droughts due to climate change (Moggi et al. 2020). Vineyards are not traditionally irrigated in Europe, but drought stress remains a problem. In irrigated crops, farmers often used delayed, organized irrigation. This strategy can increase the quality of the grapes and means that irrigation is done strategically to control the balance between vegetative growth and generative growth (Trouvelot et al. 2015), The development of precision irrigation systems has preserved soils from damage, increased efficiency in the use of resources, and reduced related costs (Moggi et al. 2020). With less pesticide use the soil quality and associated biodiversity will be improved. Healthy soil means promoting the health of the vines, improving landscape preservation as well as increasing the resilience of plants. Conservation of biodiversity can be ensured through practices such as the use of natural fertilizers and the use of pesticides only when necessary. This is only possible through management awareness of biodiversity issues and the consequent constant monitoring of vineyards' health. In addition, energy is saved by renewable energies or the development of circular economies. Examples of this trend are the use of pruning or processing waste to fuel the heating system (Moggi et al. 2020). Within the framework of economic and social sustainability, the key issues are related to the relationship between the winery and its community and the local stakeholders, for example, the importance of selecting seasonal workers coming from the local community. Suppliers are another group of stakeholders that can receive a positive impact from wine production when local wineries decide to select local growers according to an internal “zero kilometer” policy. In addition, the winery itself can be an active member of the community with a positive economic impact, supporting the local initiative and improving the relationship with local stakeholder groups such as schools and municipalities. Looking at the internal aspect of social sustainability, it is crucial to stress the importance of health and safety programs, but also the increasing space given to sustainability training, particularly for seasonal workers (Moggi et al. 2020). When a winery engages in partnership with other wineries, it is particularly important to share knowledge from those wineries that have already

implemented sustainable practices to wineries that are just beginning this sustainable implementation process. Another aspect is the gradual transition from biological and integrated production to sustainable and more complex viticulture (Moggi et al. 2020).

4.2. SWOT analysis for viticulture in a cold climate:

When applying SWOT analysis to the case studies that have been reviewed, only a few strengths appear. In Canada the use of new grape varieties that produce high-quality wine, creating jobs, and enhancing the livelihoods of residents, in addition to increasing biodiversity is mentioned. The common threats that affect viticulture in all studied cold climate countries are climate factors such as frost damage, high precipitation, disease attack, and temperature fluctuation. These threats affect viticulture productivity and decrease profitability.

Weaknesses such as the lack of political support in Bulgaria and lacking actions and information about sustainable viticulture practices could reduce the adaption of viticulture in cold climate countries. Other weaknesses mentioned are low yield that cause less profitably and the competition for land use from forest reserves, plantations, and other forms of agriculture.

There are good opportunities for viticulture in a cold climate, perform a risk assessment by collecting accurate site-specific data on key climatic variables such as temperature and precipitation. Winter protection, and vineyard management practices such as using cover crops, drainage, and adopting low-input training systems. Nutritional management of resistant cultivars is an important factor in enhancing the productivity of viticulture in cold climates. Increasing the share of high-quality wine by modernizing technology is a great way to develop wine production. Increasing wine education and programming and meeting quality and production standards (Table2).

Table2: SWOT analysis for viticulture in cold climate counties:

Country	Strengths	Weaknesses	Opportunities	Threats
Canada (Tasic2019). (Draayer & Julien 2010)	-High quality wine and then higher price. -Creating jobs, enhancing the livelihoods of residents. -Increasing biodiversity	-Lacking actions and information about the Sustainable viticulture. -Economic downturns	-Communication. -Meeting quality and production standards. -Offer a standard set of benefits for the workers	-Harsh winters -Humid summers -Fungi and pests' diseases
New Zealand (Cradock-Henry & Fountain 2019).	Not mentioned	-Less profitability	-Promoting resilience	-Climate affects. -Geological.
UK (Nesbitt et al. 2016)	Not mentioned	-Low yield	-Management strategies. -Market forces	Susceptibility to climate variability
US (Schultze & Sabbatini 2019) Zabadal et al. 2007	-Alternative grape varieties	-Less profitability. -Emotional cost.	-Risk assessment -Using wind machines. -Reduce risk	-The warming trend in cold-climate viticulture. -Precipitation -Disease
Bulgaria (Petkova 2011)	Not mentioned	Political support	-Supply of high-quality raw materials -Improved technology -Providing high-quality education. -Build good consumer wine image	-Climate effects.
Tasmania(Doyle2014)	Not mentioned	-competition for land use -Low yield	-Choosing locations with negligible risk of frost damage -Installing frost protection systems such as wind machines or overhead sprinklers -Frost analysis -disease control	-Fungal diseases. - Seasonal variation

5. Discussion

5.1. Actions that will increase viticulture opportunities in cold climate countries:

Based on the information collected in the present study, there seems to be good opportunities for growing vines in a cold climate. Despite the generally cool climate, vineyards have the potential to make significant differences in grape composition and wine quality. Grape varieties suitable for cold climates tend to produce wines of higher quality, higher aroma and a balance between sugar, acid and alcohol content along with subtle fruity flavours, which differs from varieties suitable for warm and hot climates. These differences are greater at higher latitudes depending on differences in the intensity of solar radiation and temperature. Higher rainfall increases the risk of fungal diseases, while regions with lower rainfall will need greater amounts of irrigation. Very cold regions will also face greater risks associated with delayed harvest and more rot, due to insufficient maturity. The collection and analysis of accurate site-specific data on key climatic variables such as temperature and precipitation will be important tools for producing high-quality wine and avoiding the spread of diseases.

Gustafsson and Mårtensson (2005) found that when choosing a site for vineyards, vineyards placed on a slope increase the sun's radiation. Other actions such as winter protection and vineyard management practices such as the use of cover crops, drainage, deep plowing for deep root growth, and disease control will increase viticulture opportunities in cold climate countries.

A proper selection of cultivars is a critical step for successful production. In the northern and northeastern United States, Londo and Martinson (2016) consider practices such as selecting cultivars that tolerate cold temperatures as helpful solutions to counteract the impact of a cold climate. In northeastern Italy where annual rainfall occurs in viticultural areas, Porro et al. (2022) also mentioned the possibility of using varieties resistant to fungal diseases to promote sustainable

viticulture and decrease applications of fungicides. The cool-climate varieties appear to have a higher quality and aroma but may lack alcohol due to the lower sugar content.

Gustafson and Martinson (2005) and Abad et al. (2021) found that nutritional management of resistant cultivars is a critical method, as a more balanced and productive vineyard can have good nutrient absorption and avoid nutritional deficiencies, ensuring high-quality wine. For example, nitrogen fertilization reduces the vine's winter viability, resulting in increased risks of winter damage. Phosphorous is the phytonutrient most associated with improved winter hardiness in cultivated plants. So good access to P can increase the winter hardiness of the vines.

Soil management is an important factor in enhancing the productivity of viticulture in cold climates. Gustafsson and Mårtensson (2005) and Abad et al. (2021) mentioned several soil managements practices that mitigate winter frost damage and enhance soil fertility, such as the use of cover crops for example, cover crops from the legume family. At the same time cover crops may compete with vines for water and nutrients at certain moments of the season, thus affecting the performance of vineyards.

Gustafsson and Mårtensson (2005) mentioned the use of soil covers such as mulch or strew as an alternative to cover crops. Strew should always be dried to avoid damage to the grape root. The use of foam boards, geo-textiles, and snow fences are effective methods of winter protection. But these practices will not be effective in very cold areas, like some areas of Tasmania, which have a higher risk of frost damage that can destroy the production of the vineyards.

In a cold climate such as Germany, Strub et al (2021) concluded that a change in the viticulture training system could overcome a large part of the cost disadvantages of cultivation on steep slopes. Mechanization alone cannot improve

the economic sustainability of steep slopes. Hence, the adoption of low-input training systems can make an important contribution to improving the economic sustainability for farmers and increasing viticulture efficiency.

5.2. Application of the triple bottom line on viticulture in cold climate countries:

Studies from Rouault et al. (2016) and Hallström et al. (2018) showed the extent of the environmental impacts of viticulture along the value chain. Considering the natural resources, viticulture needs land, water, labor, and energy in all stages of the production chain. The use of fossil fuels especially in primary production causes a lot of greenhouse gas emissions. The use of pesticides and chemical fertilizers can affect human health in addition to the energy consumption needed to produce and transport.

Water issues have been emphasized as a priority for wineries, but the development of precision irrigation systems has saved soils from damage, increased resource efficiency, and reduced costs (Moggi et al. 2020). With less pesticide use, soil quality will improve, and this means better vine health, better landscape preservation as well as increased plant resilience. Conservation of biodiversity can be ensured through practices such as the use of natural fertilizers and the use of pesticides only when necessary. This is only possible through increasing the awareness of biodiversity issues and the consequent constant monitoring of the health of the vineyards. In addition, energy is provided by renewable energies or the development of circular economies.

Tasic (2019) and Moggi et al. (2020) mentioned that introducing new cultivars to cold-climate regions can increase viticulture profitability, create new jobs, and reduce the use of fertilizers and pesticides. Adopting sustainable practices can improve the image of wine when it comes to consumer sentiment. For example, *Piwi* international (2022) mention Piwi varieties as sustainably and

environmentally friendly varieties for cultivation in Sweden and other cold climate counties. These varieties are resistant towards fungal diseases and require very little pesticide use. This directly protects the environment because of the decreased amount of pesticides released into the environment. The indirect contributions to the environmental protection are the saved resources needed to manufacture of fungicides. In addition, energy and carbon dioxide emissions are saved. This result in lower engine and fuel costs in the vineyards, which benefit winemakers and environmentally aware consumers.

Within the framework of economic and social sustainability, the main issues are related to the communication between the winery and local stakeholders. Wineries that collaborate on sustainable practices, through partnerships or informal collaborations, have brought to light the shared exchange of knowledge and good practices.
Draayer & Julien (2010) emphasize that the lack of knowledge about the SDGs and sustainable agriculture presents a challenge when transforming viticulture practices into more sustainable practices. Hence it is particularly important to share knowledge from wineries that have already implemented sustainable practices with wineries that are just beginning this sustainable implementation process. This knowledge must be spread not only within the country but among all countries that produce wine to implement the Sustainable Development Goals around the world. The spread of a sustainable wine production education program among farmers around the world could reorient the next generation to more sustainable wine production.

5.3. Terroir concept for viticulture in a cold climate:

From several case studies in this thesis, cold climate regions have their own natural environments, such as low winter temperature, soil characteristics, resistance varieties, and viticulture practices. According to Vaudour (2002), climatic characteristics, human factors, soil or location characteristics, and grape varieties play a major role in viticulture and wine quality. The importance of these

local scale pedoclimatic characteristics has been recognized in all cold climate case studies, for example in Bulgaria the final product must contain cultural heritage, natural and regional features local characteristics, customs, and traditions. So, vine growers have to adapt local viticulture practices, to better match the environmental conditions around them. Soil, grape variety, climate, and management largely determine the outcome of a vineyard. Hence in traditional wine cultivation regions for the winemaker, terroir simply reinforces the uniqueness of the land, but in cold climate regions terroir has become an advantage. Cold climate varieties produce wines that are lighter in alcohol, higher in aroma and with a delicate fruity bouquet, in contrast to popular wines. These varieties require less pesticide use and encourage biodiversity, making wines from cold climate regions revealing a unique character to this region. Hence terroir in cold climate is a whole ecosystem of factors that will attract younger generation who tend towards eco-friendly label wine and embrace terroir in their choices.

6. Knowledge Gaps and Suggestion for Further Study:

It was difficult to find the information related to the research topic. The author acknowledges that many aspects have not been adequately analyzed due to time constraints and information availability. This study also lacks field studies and interviews to assess cultivars and cultivation measures to confirm the results of this study, but time constraints were an obstacle. Further study should investigate the relationships between cold climate viticulture and consumer behavior towards wine produced in these regions, and how innovation could increase the opportunity for viticulture in a cold climate and promote more sustainable viticulture production.

7. Conclusions:

Climate change creates a new opportunity to shift viticulture to new cold regions. Environmental factors vary widely from region to region. The main limiting factor affecting the productivity of viticulture in cold climates is spring frost which can destroy the production of the vineyard because the flowers and leaves can be damaged, and this will reduce the yield.

High annual precipitation is another factor affecting viticulture yield and requires several actions such as the use of disease resistant cultivars, to promote sustainable viticulture by reducing the number of plant protection treatments.

Soil management also affects the productivity of viticulture depending on many factors, such as characteristics of crop cover, soil type, climate, and other characteristics of the vineyards.

Given the natural resources, viticulture needs land, water, labor, and energy at all stages of the production chain. The use of fossil fuels especially in primary production causes a lot of greenhouse gas emissions that will increase the greenhouse effect. The use of pesticides and chemical fertilizers can affect human health as well as energy consumption and may have many effects on the environment.

The literature reviewed in this study (Canada, Tasmania, UK, Sweden, Bulgaria, Germany, New Zealand, and the cold climate region of the United States) shows that despite the harsh climate that includes spring frosts, temperature fluctuation, high rainfall, short summers, and cold winters, there are good opportunities for building sustainable viticulture in a cold climate region because many locations present topographical complexity providing an average climate suitable for viticulture. Sustainable viticulture in cold climates should achieve the three dimensions of sustainability, in the environmental dimension practices such as (1) site selection, (2) an adaptation of new resistant cultivars, (3) mechanization, (4)

change of viticulture training system, (5) good soil management, (6) proper fertilization management, and (7) use of renewable energy should be applied.

In the economic dimension (1) improving energy and water efficiency (reducing cost). (2) more sustainable training in agriculture and innovation. (3) creating a new network in the supply chain to improve economies, and (4) brand reputation.

In the social dimension, cold climate viticulture would enhance (1) local cooperation and communication and (2) create local employment opportunities, and (3) promote healthy wine production that (4) ensure respect for family standards, values , and beliefs. It should also support local farmers (5) and (6) promote worker health.

The policies and mechanisms have to balance economic, social, and environmental aspects to encourage sustainable integrated viticulture in cold climate regions.

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Appendix 1.

Popular Science Summary of Master Thesis:

Climate change creates a new opportunity to shift viticulture to new cold regions. The main limiting factor affecting the productivity of viticulture in cold climates is spring frost which can destroy the production of the vineyard because the flowers and leaves can be damaged, and this will reduce the yield. High annual precipitation is another factor affecting viticulture yield and requires several actions such as the use of disease resistant cultivars, to promote sustainable viticulture by reducing the number of plant protection treatments. Soil management also affects the productivity of viticulture depending on many factors, such as characteristics of crop cover, soil type, climate, and other characteristics of the vineyards.

Given the natural resources, viticulture needs land, water, labor, and energy at all stages of the production chain. The use of fossil fuels especially in primary production causes a lot of greenhouse gas emissions that will increase the greenhouse effect. The use of pesticides and chemical fertilizers can affect human health as well as energy consumption and may have many effects on the environment.

This thesis focusses on viticulture in a cold climate and how climate change could contribute to more sustainable wine production. This research investigates if wine production in cold climates could create a dynamic balance between productivity and the consumption of natural resources to implement more sustainable wine production in cold and cool climate regions

There are good opportunities for building sustainable viticulture in a cold climate region because many locations present topographical complexity providing an average climate suitable for viticulture. Sustainable viticulture in cold climates should achieve the three dimensions of sustainability, in the environmental dimension practices such as (1) site selection, (2) an adaptation of new resistant cultivars, (3) mechanization, (4) change of viticulture training system, (5) good soil management, (6) proper fertilization management, and (7) use of renewable energy should be applied.

In the economic dimension (1) improving energy and water efficiency (reducing cost). (2) more sustainable training in agriculture and innovation. (3) creating a new network in the supply chain to improve economies, and (4) brand reputation.

In the social dimension, cold climate viticulture would enhance (1) local cooperation and communication and (2) create local employment opportunities, and (3) promote healthy wine production that (4) ensure respect for family standards, values , and beliefs. It should also support local farmers (5) and (6) promote worker health.

Cold climate varieties produce wines that are lighter in alcohol, higher in aroma and with a delicate fruity bouquet, in contrast to popular wines. These varieties require less pesticide use and encourage biodiversity, making wines from cold climate regions revealing a unique character to this region. Hence wine from a cold climate will attract the younger generation who tend towards eco-friendly label wine in their choices