A Bioeconomic Analysis of Climate Change Impacts on Grape Growers in the Niagara Peninsula

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ABSTRACT

This study evaluates the economic impacts of future climate change (2015-2044) on representative vineyards in the Niagara Peninsula, Ontario. An integrated Bio-Economic Approach was used to evaluate the Net Present Value (NPV) of grape growers. First, three future climate scenarios (Median, Warm/Dry, Cold/Humid) and two conditions (with and without atmospheric carbon dioxide (CO_2) enhancement) were selected. Climate scenario data were obtained from the Regional Climate Model system RegCM v.4. Second, yield data were obtained through simulation with the Cropping Systems Simulation Model (CropSyst). Finally, the Net Present Value (NPV) was estimated. Land allocation was determined exogenously. Six wine-grape varieties (Chardonnay, Riesling, Cabernet Sauvignon, Cabernet Franc, Merlot, and Pinot Noir) were selected for the study. The results indicate that net present value, output, economic vulnerability and financial management tools varied with each climate scenario and condition. The direction and magnitude of the impacts changed as CO_2 enhancement conditions varied by crop. Even under the worst climate condition of Cold/Humid with the absence of CO_2 fertilization effects, the only crops that had a relative economic advantage were Cabernet Franc and Cabernet Sauvignon (red varieties). The returns on the white grape varieties were significantly lower for all scenarios. The results indicate that the Agristability program helped absorb the variability in NPV and stabilized income, but did not ensure producers'

financial stability from the risks of climate change. Financial risk management tools would help growers to increase their financial strength, have flexibility in their choice of adaptation options, and reduce their economic vulnerability. These management tools, and should remain profitable, and has to as well as including e an environmental decisions such as increasing soil fertility.

A. RÉSUMÉ

Cette étude a pour objectif l'évaluation de l'impact économique des futurs changements climatiques (entre 2015 et 2044) sur des vignes représentatives dans la péninsule du Niagara, Ontario. Une approche Bio-économique intégrée a été utilisé pour évaluer la valeur nette actuelle (VNA) des viticulteurs. Tout d'abord, trois futurs scénarios climatiques (médian, chaud/sec, froid/humide) ainsi que deux conditions (avec et sans amélioration atmosphérique du dioxyde de carbone (CO_2)) ont été sélectionnés. Les données des scénarios climatiques ont été obtenues à partir d'un modèle climatique régional RegCM système v.4, Deuxièmement, les données des rendements ont été obtenues par simulation avec le modèle de simulation du système de recadrage (de CropSyst). Enfin, la valeur nette actuelle (VNA) a pu être estimée. L'allocation des terres a été déterminée d'une manière exogène. Six variétés de raisins de cuve (Chardonnay, Riesling, Cabernet Sauvignon, Cabernet Franc , Merlot et Pinot Noir) ont été choisis pour l'étude. Les résultats obtenus grâce aux outils de la valeur nette actuelle, indiquent que la vulnérabilité économique et la gestion financière varient avec chaque scénario des conditions climatiques. La direction et l'ampleur des changements des conditions d'amélioration du CO_2 varient selon les cultures. Même dans les pires conditions climatiques, froid / humide, avec l'absence d'effets de fertilisation du CO_2, les seules cultures qui ont eu un avantage économique étaient le Cabernet Franc et le Cabernet Sauvignon (variétés

rouges). Les rendements sur les cépages blancs étaient significativement plus faibles dans tous les scénarios. Les résultats indiquent que le programme Agro-stabilité a contribué à absorber la variabilité de la VNA et a stabilisé le revenu, mais n'a pas assurer la stabilité financière des producteurs contre les risques des changements climatiques. Des outils de gestion des risques financiers pourraient aider les producteurs à accroître leurs solidité financière, leurs offrir la flexibilité dans le choix des options d'adaptation, de réduire leur vulnérabilité économique, et de rester rentable, et doit inclure des décisions environnementales telles que l'augmentation de la fertilité des sols.

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LIST OF ABBREVIATIONS

GHGs: Greenhouse Gases

VQA: Vintners Quality Alliance

GGO: Grape Growers Ontario

WCO: Wine Council Ontario

WGAO: Winery and Growing Alliance of Ontario

OWS: Ontario Wine Society

CCOVI: The Cool Climate Oenology and Viticulture Institute

VRIC: Vineland Research and Innovation Centre

PP: Pilot Plateau

CropSyst: Cropping Systems Simulation Model

NPV: Net Present Value

IBEM: Integrated Bio-economic Modelling

RegCM: Regional Climate Model

GCMs: General Climate Models

ClimGen: Climate Generator

GDD: Growing Degree Days

MC: Monte Carlo

CAIS: Canadian Agricultural Income Stabilization

NVSP: New Vineyard Support Program

BY: Base Yield

AY: Average Yield

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CHAPTER 1

BACKGROUND AND INTRODUCTION

1.1. BACKGROUND

According to the latest scientific research, global warming is unequivocal; evidenced by rising average air and ocean temperatures, widespread snow and ice melt, and increasing average sea level (IPCC, 2007a). New evidence also indicates that the cause of global warming is rising greenhouse gas concentrations over the last 50 years which are largely anthropogenic, i.e. human induced, and have driven subsequent, non-linear warming trends (IPCC, 2007b). The period from 1995 to 2006 marks one of the hottest on record, with 11 of 12 years ranked among the 12 warmest years in the past 150+ years (IPCC, 2007b). Over the course of the next century even if the greenhouse gas concentration is held at its current level, due to the slow response of climate processes and feedbacks, the continuation of warming is inevitable. The threat of extreme weather is also expected to increase. Most land areas will experience warmer and fewer cold days and nights, warmer and more frequent hot days and nights, more frequent heat waves and heavy precipitation events; as well as increased likelihood of drought, tropical storm, and high sea level (IPCC, 2007a).

There is a widespread consensus that global warming and climate change are serious problems (Anthoff and Tol, 2012) which can be explained with either direct or indirect human activities (Hardy, 2003; IPCC, 1995). The concentration of atmospheric carbon dioxide (CO_2) is the most influential greenhouse gas for global warming, which has increased from 280 ppm in pre-industrialized period to 379 ppm in 2005 (IPCC, 2007a). The impact of elevated CO_2 levels can result in increasing volatility of future weather conditions i.e. small increases in average temperature due to climate change will result in dramatic changes and frequency of stormy weather that result in heavier precipitation, particularly in the northern hemisphere (Finnis et al., 2007). According to future emission scenarios, the average global surface temperature is likely to increase by 1.1 to 2.9 °C in the best climate scenario and 2.4 to 6.4 °C in the worst climate scenario during the 21st century. The effects of an increase in global temperature have been estimated to include a rise in sea level between 0.18m-0.59m and a change in the amount and pattern of precipitation in the more northern latitudes (Jian et al., 2007; IPCC, 2007a). Being in northern latitude, Canada has begun to feel the adverse effects where changes are expected to be greatest. Future predictions of the mean temperature and precipitation show a rise between 3.6°C and 7.5°C, which is a 9.1%-17.8% increase by 2080 respectively in Canada (Okey et al., 2012). A study predicted that overall impact of climate change on forests, fish population and agriculture could be extreme (PEI Department of Fisheries, Aquaculture, and Environment, PEI Department of Development and Technology, 2001).

Global climate change has had an impact on the world economy (Houghton et al. 1996). Climate change has the potential of affecting all economic sectors. However, the agricultural sector is the most sensitive sector to changing climate due to its dependence on natural weather patterns for its productivity (Watson and Moss, 1996; Rosenzweig and Hillel, 1998). Significantly increasing temperature, large changes in rainfall or degradation of soil would have negative impacts on global agriculture in the form of declining crop yields and prompting food prices to increase (Parry et al. 1999; IPCC, 2001). In addition, global climate change might dramatically affect agriculture in terms of flood, drought, and frost. If climate change causes crops to fail, then population may suffer deprivation (Doering et al., 2002). Productivity in the agricultural sector is closely related to atmospheric carbon dioxide (CO_2) concentration. The impact of climate change is not only in terms of changes in agricultural output but it has also the economic consequences on farm profitability, agricultural supply and demand, trade, price, (Kaiser and Drennen, 1993) and the value of agricultural land (Mendelsohn et al., 1994). In addition, energy supply and demand, buildings and roads, recreation and tourism, as well as human health will be affected (Herrington et al., 1997).

The agricultural sector is not only linked to many other sectors but food and fiber production is essential for sustaining and enhancing human welfare. Therefore, if the necessary climate change mitigation strategies i.e.

greenhouse gas emissions (GHGs) reduction, are not adopted, then market failure is inevitable. Failure to adaptation would result in socially inefficient production. This would result in negative effects on consumer welfare (McCarl et al., 2001; Kaiser and Drennen, 1993; Adams et al., 1998).

"*Over the last thirty years, integrated assessment of climate change and future agricultural production has been carried out in a number of different ways*." (Doering et al 2002, p.5). While the causes of climate change is among the most debated topics, climate change is predicted to have a significant impact on agriculture. This is due to the combined effects of elevated temperatures, increased likelihood of droughts, and reduced crop water availability (Yanda and Mubaya, 2011; Chiotti and Johnston, 1995).

Two categories of approaches to address climate change are identified in the Kyoto protocol; mitigation and adaptation. Mitigation is an action that limits global climate change through the reduction of GHG emissions. On the other hand, adaptation includes the ability to adjust systems to the effects of climate change or to respond to its impacts (IPCC, 1990). Farmers have tried to adjust their production decisions by taking climate change into account. Their main concern is managing themselves in terms of timing, magnitude, variability (Rosenzweig and Hillel, 1995). It is important to quantify and monetize the economic impacts of climate change on the agriculture sector.

However, it is not certain that net future effects of climate change will be beneficial or harmful to farmers in different regions (Hardy, 2003). This expectation for agriculture output threatens global food security (International Food Policy Research Institute, 2009). It is difficult for farmers to be sufficiently aware of the potential consequences of climate change and/or to prepare alternative production strategies for future periods (Mendelsohn, 2001).

There may be significant opportunities for Canadian agriculture in a warmer climate as opposed to other parts of the world. These opportunities will only be available if sufficient precipitation continues in the food-producing areas and the necessary adaptation measures are applied in time (Lee and Murdock, 1998).

1.2. INTRODUCTION

Climate change poses a serious challenge to society. From an economic perspective, this issue is particularly complex because the potential outcomes are not precisely defined, they span over the medium-long term, and failure to react may produce major changes (Stern 2006). While climate change may affect all sectors of the economy, some face more risk than others. The agricultural sector stands out because warming temperatures and changing precipitation patterns directly affect crop production. Wine grapes have garnered particular interest because they are long-lived crops that can only be grown under a specific set of climate conditions within a narrow geographic region. By that, they are distinctly vulnerable to climate change (Jones et al. 2005).

"*Despite worldwide coverage of climate change impacts, there is intra-sectoral and inter-sectoral variation in vulnerability depending on location, adaptive capacity and other socioeconomic and environmental factors*" (Aniah et al, 2014 p.693). For example, the agricultural sector in Canada and the US are believed to benefit from gradual climate change due to the greenhouse effect and the warmer climate (Tol and Langen, 2000; IPCC 2001; Weber and Hauer, 2003). This is especially important for grape production and the related wine industry because of its sensitivity to climate, its high site specificity and the longer time frame of decisions associated with perennial crops (Jones et al, 2005; White et al, 2006; IPCC, 2007a). Therefore, a warmer climate could create a favorable environment for perennial crops i.e. vine-grapes in Canada. However, Lemman and Warren (2004) indicate that the net impacts are uncertain and vary with different varieties of grape. Warmer temperature may increase the length of the growing season; but it could also lead to crop damage resulting from heat stress, water and pest problems. Canada has massive water resources generating adequate soil moisture; however, climate change is expected to remarkably impact on them. It may particularly decrease lake levels and ground water levels while it may enhance higher evapotranspiration which may trigger moisture deficits across the country (Koshida and Avis, 1998; Lonergan, 2004). Water availability and especially groundwater level are also major elements in viticulture production; therefore decreasing levels of water can negatively affect all grape growing areas especially during the summer season.

On account of its climate, Southern Ontario is one of the best wine producing regions in Canada (Shaw, 2005). The Niagara Peninsula produces over 70 percent of the wine grapes in Canada, the country's most valuable fruit crop (Agriculture and Agri-food Canada, 2014). However, the Niagara Peninsula is predominantly on the margins of climate suitability for viticulture, with roughly 52% of the total area falling into the coolest and hottest ranges for wine grape production (Agriculture and Agri-food Canada, 2014). Furthermore, the wine industry is one of the fastest growing agri-businesses in the Niagara Region and provides numerous direct and indirect opportunities for growth and development (Caldwell, 2000).

If $C0_2$ levels were to double, it has been estimated that Ontario's average annual warming would be between 2 and 5°C by the latter part of the 21st century. Moreover, the increases will probably be greater in the winter than in the summer. Even if the greenhouse gas concentration was stabilized at that point, temperature would continue to increase with a possibility of an overall warming of 3° to 8°C. (Chiotti and Lavender, 2008). These changes would significantly decrease the duration of the annual snow season and lengthen the growing season. It could increase the frequency and severity of extreme heat events in a summer and implies that changes in rainfall matters, soil moisture in the southern part of grape varieties (Mortsch and Mills, 1996).

Climate projections suggest that Ontario will become warmer with some areas becoming drier and other areas wetter, by the end of the 21st century, which could render the profitability of the coolest wine variety industry at risk. However, specific vineyard management techniques could mitigate some of the effects of climate change on wine grape production in this region. When a grape variety is grown in a cool region, the wine is unbalanced with suboptimal sugar levels and unripe flavors. On the other hand, if a region's climate is too hot, the wine is again unbalanced with overripe flavors and low retention of acids (Jones et al. 2005). Some of the extreme climate conditions, such as winter freezes, spring and fall frosts, and extreme heat, drought, floods can devastate viticulture (Jones, 2010).

There is substantial research on the potential impact of climate change on the wine industry and the grape growers from around the world (Nemani et al., 2001). Some of the literature concentrates on the effects of global warming on wines with respect to bottle prices and wine grape yields; while other studies consider the impact on the economic returns to wine grape growers (Gatto et al., 2009). Most studies rely on monthly weather observations due to limited data availability at more frequent intervals; even if the daily climatic record is better suited to explain changes in grape yield. This study will investigate the impact of climate change on wine grape yield in the Niagara Peninsula using fine-scale daily temperature, precipitation, and solar radiation data. Furthermore, the paper also forecasts the potential impacts of future climate change on wine grape yield in a simulation context.

The major elements that affect the quality and quantity of grapes and wine produced are weather and climate. Climate variability has already affected wine style, wine/grape yields and quality differences in Canada (Jones and Hellman, 2002; Jones, 2004; Battaglini et al. 2008). The three main climatic conditions for quality grape production are identified by White et al (2009): (1) adequate heat accumulation; (2) low risk of severe frost damage during the growing season; and (3) the absence of extreme heat. The importance of potential weather and climate effects on grape growing is based on how these will affect the growers and how the growers may respond (Jones, 2004; Battaglini et al., 2008).

1.2.1. PROBLEM STATEMENT

The inherent uncertainty associated with climate change and/or variability will make it challenging for farmers in the Niagara Peninsula to identify optimal adaptation options for viticulture and prepare response plans for the future. To provide insight into potential adaptation strategies, the following questions will be addressed: What are the possible impacts of varying climatic conditions on the quality of most popular varieties of grapes? (more or less frost-free days, higher or lower growing degree days, precipitation etc.). Which varieties of grape are most adaptive to climatic change? Which varieties are profitable for wine production? What is the economic impact of climate change on grape growers in the Niagara Peninsula? What types of federal/provincial programs or policies may assist growers to adjust to climate change?

1.2.2. OBJECTIVES OF STUDY

The primary objective of this study is to estimate the economic impact of projected climate, yield, cost, and prices changes on the production of a representative vineyard in the Niagara Peninsula region of Ontario using an integrated bio-economic approach. The analysis captured both the impact of historical weather records on the viability of production and the impact of the market price on wine. The Cropsyst simulation model was adopted to evaluate historical changes in climatic variables on the yield of different grape varieties (Stöckle et al. 2003). A range of future climatic scenarios was developed to predict the impact of climate change on yield of different grape varieties and their resulting economic impact. The main objectives are;

i. To estimate the impact on grape yield of future climate scenarios using a crop simulation model.
ii. To simulate each wine grape variety price and costs.
iii. To develop a Net Present Value model that included several insurance options.
iv. To evaluate the impact of various climate scenarios and changing market conditions on the present value of net farm income of grape growers and to assess their economic vulnerability.
v. To identify adaptation strategies and assess the role of insurance as a financial risk management tool; and finally
vi. To estimate the impact of provincial policies on the economic situation of grape producers in the Niagara Peninsula.

Due to its geographical location, the Niagara Peninsula is expected to have warmer climate conditions than today; so cool climate wine grape yield which are most popular in this region, are expected to decline in the future. Due to the declining yield, profits (net return) on grape production would be expected to decrease, if producers will not adopt different varieties that are more profitable.

1.2.3. ORGANIZATION OF THE STUDY

Chapter 2 presents the scope of the study starting with a historical background of the Niagara wine growing region and brief information about the wine sector in the Niagara Peninsula. A short review of the literature related to climate change effects on grape production follows in Chapter 3. A review of methods, description of the material and analytical method used in the study are presented in Chapter 4. The results and the discussion about their implications are given in Chapter 5. The conclusions, recommendations, and policy implications of the results are addressed in Chapter 6.

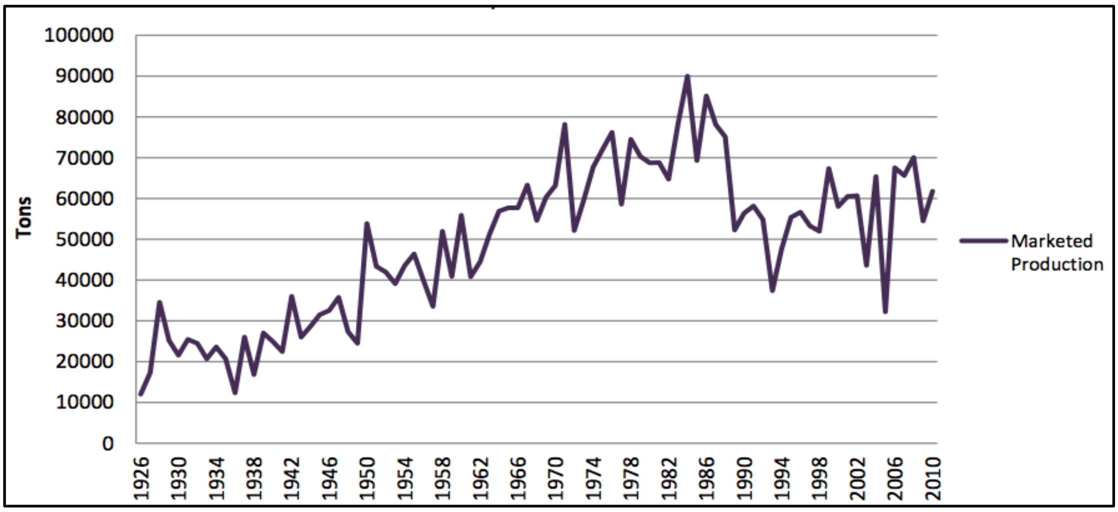
CHAPTER 2

SCOPE OF THE STUDY

2.1. HISTORICAL BACKGROUND

The Canadian wine industry in southern Ontario has existed for over a century. In order to produce better wines growers have left the local varieties such as Labrusca and Concord in favor of more quality vines like Vitis Vinifera and European Hybrid. Figure 1 illustrates the marketed output of grapes (table and wine) in Ontario. There is a difference in the overall growth in annual yields during the first period from 1926 to 1988 and the second period from 1988 to present. The second period was after the Canada-US Free Trade Agreement (CUFTA). In the second period, total yield decreased drastically after the CUFTA due to a replanting program to increase the quality of vinifera varieties (Pelling and Hira, 2012).

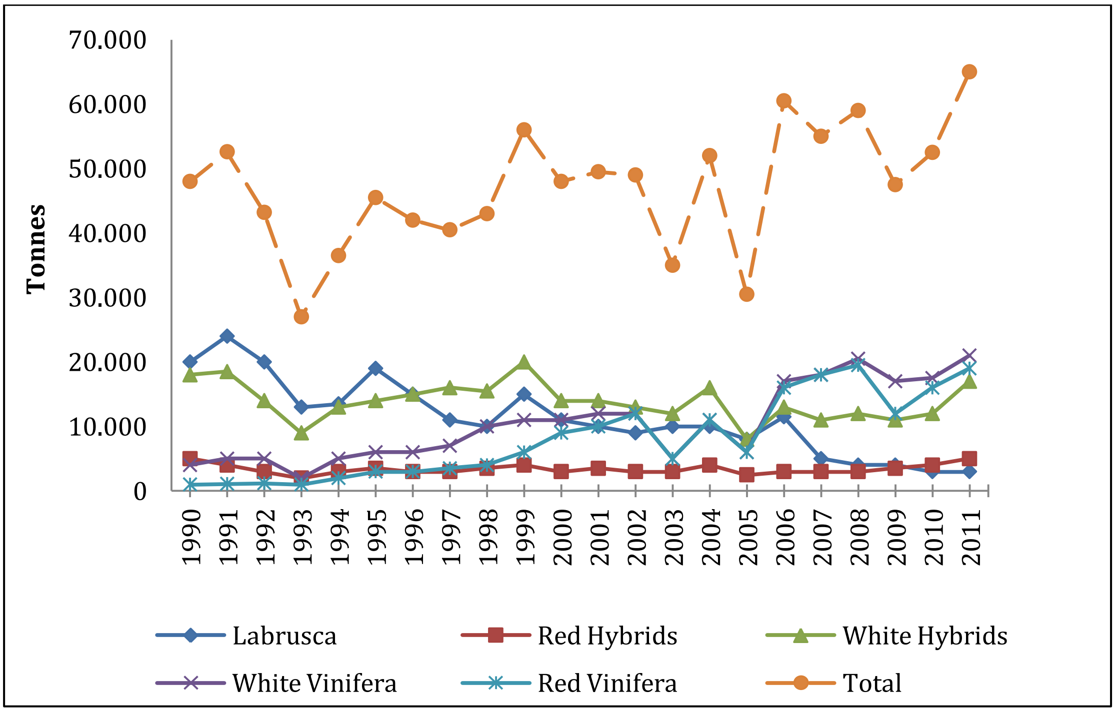
Figure 1: Output of Grapes, Ontario 1926-2010 (includes table and wine grapes)



Source: Statistics Canada CANSIM Table 0010009 Area, production and farm value of fresh and processed fruits

Figure 2 illustrates the breakdown of grape variety purchases by wine processors from Ontario sources over the last two decades. There is some volatility in the overall level of purchases; most notably at 2005, but the purchased tonnage is increasing. Over this period, the use of local Labrusca grapes has diminished almost entirely, while Red and White Vinifera have increased.

Figure 2: Grape Purchases by Processors



Source: Grape Growers Ontario

2.2. GEOGRAPHICAL LOCATION AND VINEYARD GEOLOGY

Regions that are located between the 41st and 44th degree north latitude are the most important viticulture areas in the world. This latitude includes such wine growing regions as the Oregon State's wine region, California's Mendocino Valley and Washington State's Yakima Valley, the Chianti Classico region in Italy, the Provence and Langeudoc-Roussillon in France, the Rioja region in Spain (Grape Growers Ontario, 2010). The two largest wine grape producing regions in Canada are the Niagara Peninsula in southern Ontario and the Okanagan Valley in southern British Columbia. They are located at the 43rd north latitude. There are also a growing number of small producers of grapes and wine in southern Quebec and Nova Scotia as shown in Annex 1. Compared to other viticultural areas in Canada, Ontario produces the largest percentage of Canada wine from 13,600 acres of wine grape vineyards with another 5000 acres devoted to grapes for juices, while British Colombia has approximately 8000 acres ("Niagara Peninsula", 2014). Although the Niagara region's most important economic activity has always been grape production for the past 150 years, the industry has only recently been acknowledged for the quality of its wine at national and international competitions (Shaw, 2005). Grape growing regions can be recognized by three main resource factors; geographic and climatic, physiography and soil capability. Annex 1 shows the relative location of the Niagara Peninsula in Ontario.

The Niagara Peninsula is a distinct geographical region located in southern Ontario that lies between two of the five Great Lakes; Lake Ontario to the north and Lake Erie to the south (Annex 2). Indeed, the Niagara region is not a true peninsula; the Niagara River connects the two great lakes and acts like a narrow strait. As a result, there is always accessible, abundant fresh water for agriculture which is an advantage for growing grapes in Ontario (Ontario, Regional Municipality of Niagara, 2014).

The Niagara Peninsula is divided into two broad areas according to soil and bedrock characteristics: (1) the Niagara Escarpment; and (2) the Haldimand Clay Plain (Annex 3) (Haynes, 2000). The Niagara Fruit Belt, located on the Lake Iroquois Plain, is suitable for grape growing because its soil is well-drained sandy loam since it is adjacent to the Lake Ontario. This bordering ensures water to young vines in the drier months of July and August (Shaw, 2005).

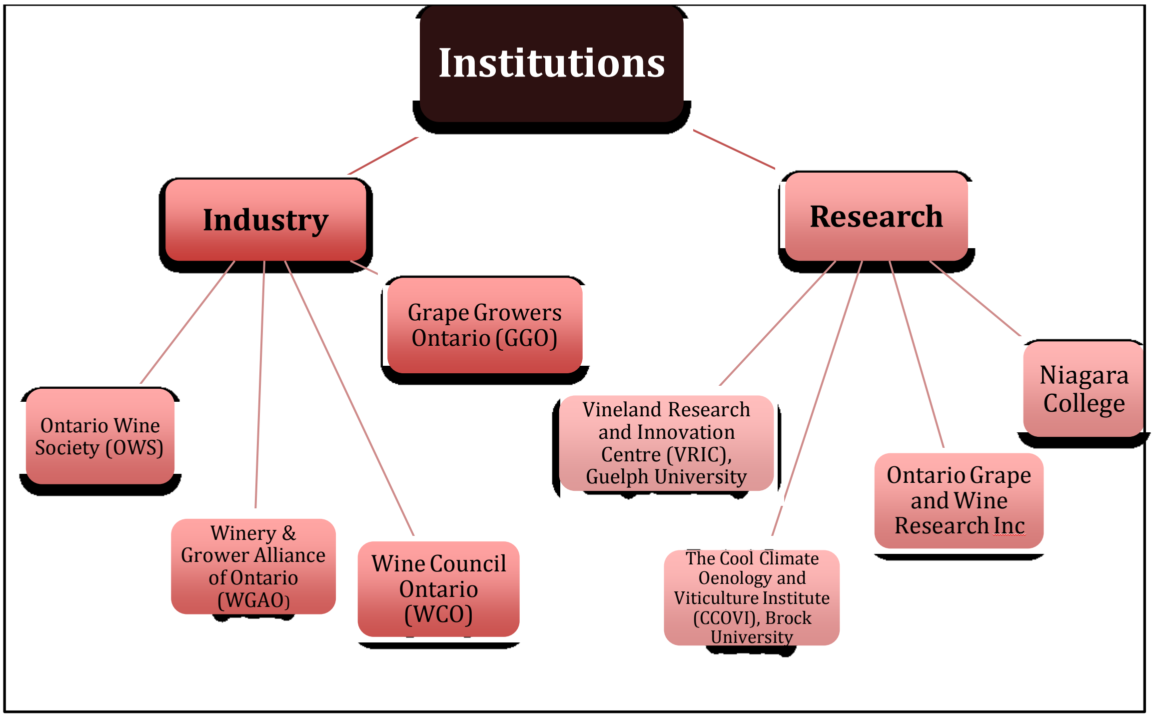
Several glacial and interglacial events have occurred in the Niagara Peninsula over the last 200,000 years. These events shaped the layers of sedimentary rock and ancient reef structures of the Niagara Escarpment (VQA Ontario). The physical setting of a vineyard's geology, which includes the physiography (bedrock) and soil, is an important factor in wine quality. Vineyard geology includes parameters such as temperature, elevation and slope characteristics, water availability, drainage and their correlations (White, 2003). This geology influences vine ripening and the wine's taste (Maltman, 2003; Goode, 2005). The Niagara Peninsula also has an ideal mesoclimatic condition for grape production, such as distance from the lakes, less than 3% slope, which takes advantage of sunlight in the growing season and air flow patterns. As a result, the Niagara Peninsula has the largest number of varieties of Viticulture in Canada (VQA Ontario).

Grape growing depends on some specific climatic characteristics such as frost free days (mean temperature above -2° C); average growing degree days and July mean temperature; and precipitation (rainfall, freezing rain, snow, ice pellets and hail) (Annex 4). "*The climate in Niagara for growing grapes is ideal, not extremely hot or cold, frost-free, usually mild weather, warm in summer and cool in winter. Thus, the Niagara viticultural area has distinguishing characteristics of mesoclimates, topographies and soil which are favorable for various fruits and grape cultivation*" (Shaw, 2012 p.111). According to climatic statistics of the Niagara Peninsula, grape cultivation average growing degree days are 1,413, frost free days are 198, July mean temperature is 22.3°C, the most dominant growing season is between April to October and the precipitation value in the growing season is 546 mm (VQA Ontario).

2.3. INSTITUTIONAL FRAMEWORK

The institutional structure of the grape and wine industry in Ontario has been organized to be conducive to innovation. Existing institutions can be divided into two categories: industrial and research (Figure 3).

Figure 3: Ontario Wine Institutional Structure



Source: Compiled by the Author

The industrial category includes the Grape Growers Ontario (GGO), Wine Council Ontario (WCO), Winery and Grower Alliance of Ontario (WGAO), and the Ontario Wine Society (OWS). GGO is a member-funded marketing board and is important in all aspects of production and marketing. The GGO is an umbrella organization that includes all growers and nearly every industry stakeholder. The GGO has six hundred members. There are two organizations to represent processors (wineries). These are the WCO; which promotes Vintners Quality Alliance[1] (VQA) certified wines; and the WGAO, which represents larger wineries that produce both VQA and International

[1] Vintners Quality Alliance, or VQA, is a regulatory and appellation system which guarantees the high quality and authenticity of origin for Canadian wines made under that system in Ontario - Made with 100% Ontario-grown grapes

Canadian Blend[2] (ICB) wines. Though the WCO exclusively represents VQA producers, WGAO wineries continue to produce the majority of VQA wines in the province. Working in cooperation with the WCO and the WGAO, the GGO's major role is to annually negotiate minimum prices for grapes sold to manufacturers within the province (Mytelka and Goertzen, 2004). On the research side, the Ontario wine industry receives research support from local academic and publicly funded scientific institutions such as Niagara College, The Cool Climate Oenology and Viticulture Institute (CCOVI), Brock University; the Vineland Research and Innovation Centre (VRIC), and University of Guelph. These research institutions focus almost exclusively on biological and technological innovations related to maximizing quality and yield of Ontario vineyards. For example, Brock University experiments are routinely carried out in vineyard settings in order to test adaptation and growing techniques that are particular to the Ontario climate (Coventry et al., 2005). Ontario Grape and Wine Research Inc. has three shareholders, GGO, WCO, WGAO, who negotiate how industry levies ought to be invested in research program at VRIC and CCOVI.

2.4. QUALITY AND PRICING MECHANISM

Grape quality in Ontario is determined by the relative level of brix (sweetness), which tends to negate certain qualities for example acidity,

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[2] ICB: Ontario wineries must use a minimum of 40% domestic content, with a minimum of 25% Ontario grapes in an individual bottle of wine

which normally receive emphasis in the winemaking industry. As a safeguard, the classification of wine as VQA or non-VQA serves to partially correct the shortcomings associated with the level of brix as the quality indicator of the input. Brix level is determined for each grape varieties. Annex 5: Panel A-F shows that how brix level affects the 2013 grape pricing.

Every year grape prices are negotiated between the marketing board and winery related institutions due to their brix ranges (sugar content). Since 2010 pricing negotiations are co-arranged by WCO, WGAO, and GGO. These negotiations have been attributed to two developments. The first was the adoption of the "*pilot plateau (PP) pricing model*" developed for the industry by GGO on selected varieties; i.e. Chardonnay, Riesling, Cabernet Sauvignon, and Cabernet Franc (Pelling and Hira, 2012) annually or multi-annually. Table 1 compares regular pricing and PP pricing on 6 different grape varieties' brix levels.

Table 1: Pricing and Brix level of Various Varieties of Grapes

	Riesling		Chardonnay		Cab. Sauv.		Cab. Franc		Merlot		Pinot Noir	
	$/ton	°Bx	$/ton	°Bx	$/ton	°Bx	$/ton	°Bx	$/ton	°Bx	$/ton	°Bx
2011 2012	$1,396 $1,417	19.1°	$1,424 $1,445	21.0°	$1,875 $1,875	21.4°	$1,676 $1,676	21.3°	$1,894 $1,894	22.0°	$1,933 $1,933	21.0°
Plateau Pricing	$1,200	17.3°-18.5°	$1,200	19.1°-20.4°	$1,300	18.2°-20.8°	$1,300	18.8°-20.7°	n.a.	n.a.	n.a.	n.a.

Source: Grape Growers Ontario 2011/2012 annual report

[a]PP pricing was determined for 2 years agreement (2011-2012) according to 2010 base pricing for four varieties.

[b]PP Prices are calculated using international bulk wine prices, and a cost of production formula

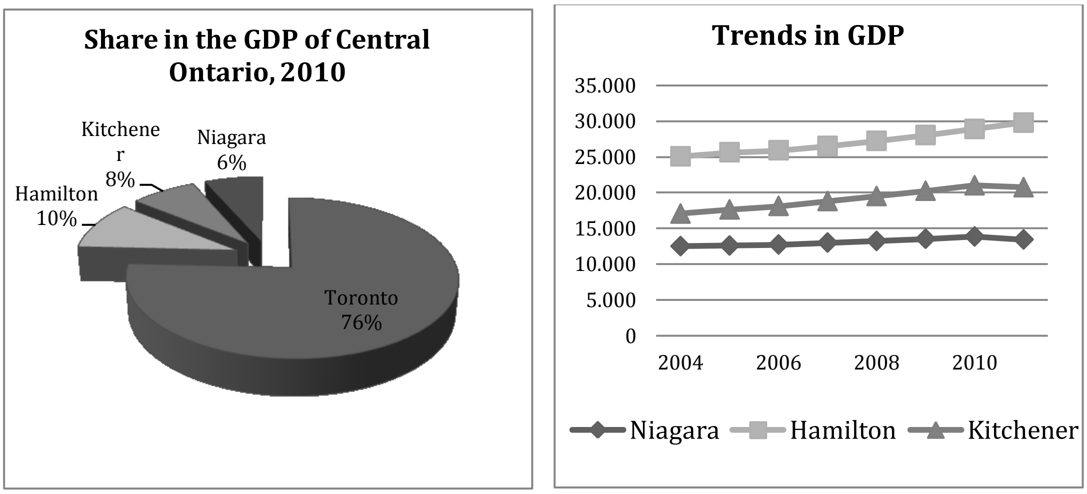
[c]Regular grape prices indicate the most qualified grapes according to brix level

The goal of PP Pricing is that more grapes that fall in the lower brix range will be purchased with this price. Also, the Brix level each year is based on a five-year rolling average. The intent of PP pricing is to create an opportunity for wineries to access grapes in lower brix ranges at a lower price from GGO. This was done because of legal restrictions that 40% of a winery's overall blended content to be from Ontario grapes with a minimum 25% domestic content within each bottle. Therefore, plateau grapes have no restrictions on tonnage. The second is that WGAO started to establish closer relationships with the grower community (Cattell, 2012; Pelling and Hira, 2012).

2.5. ECONOMIC AND INDUSTRIAL PERSPECTIVE

Favorable climate conditions and fertile soils allowed the Niagara Peninsula to be a major grape producing region and its wine industries have grown to be a substantial catalyst for regional economic development. "*Niagara is home to approximately 90 wineries, and almost 400 grape growers"* (Penney et al. 2012, p.36). Each acre of grapes generates $30,945 to the province of Ontario in economic value per year. The wine industry in Ontario generated $674 million in retail sales in 2013. "*Ontario's VQA wine industry contributed $191 M to the economy and $10 M to tourism receipts in 2010, and created an additional 1,300 jobs between 2007 and 2011"* (Penney et al., 2012, p.36). In 2007, the wine industry generated $529 million in tax revenues for the province. As a tourist destination, Niagara attracts nearly 20 million visitors annually; over 1 million people visit the province's wineries each year (Wine Council of Ontario, 2011). Municipality of Niagara has 6% of Central Ontario's GDP. It is currently fourth highest after Toronto (76%), Hamilton (10%) and Kitchener (8%) (Figure 4).

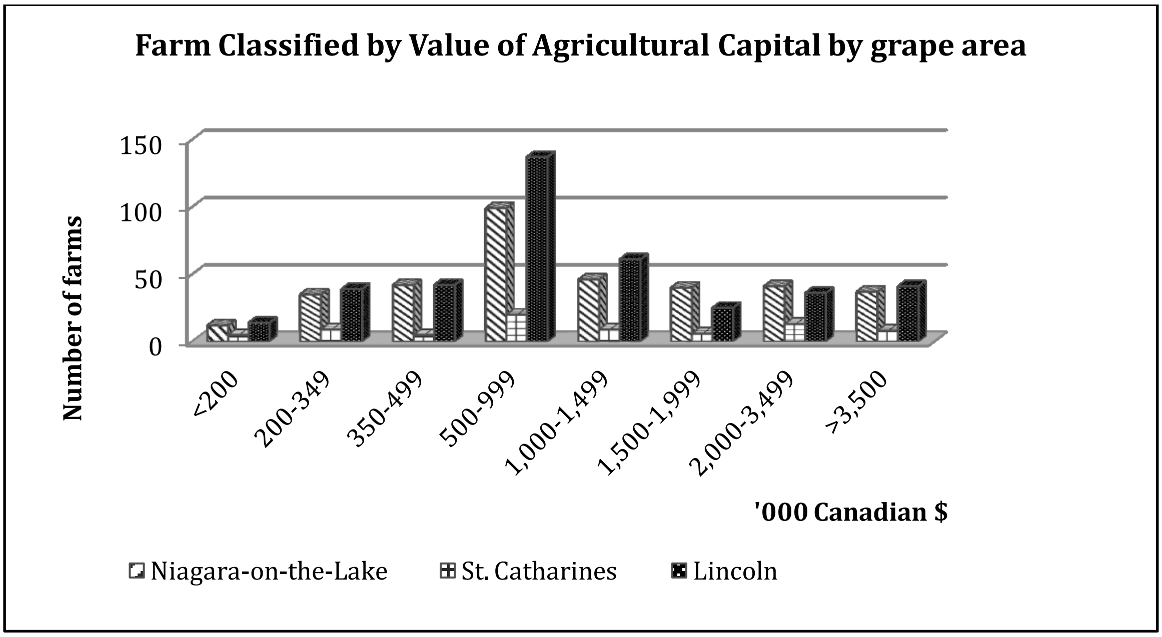
Figure 4: Selected Economic Indicators for Niagara Peninsula



Source: Based on data from "The Conference Board of Canada, Metropolitan Outlook" http://www.conferenceboard.ca/e-library

The Niagara Region is a significant contributor to the economic impact of agriculture in Ontario. Of the 49 regions, counties and districts in Ontario, Niagara is ranked the thirty-eighth in geographic size; however, it is the twenty-fifth in total area farmed, the tenth in the number of farms and the fourth in gross farm receipts. It ranks first in terms of the average gross farm receipts per acre. Agricultural production plays an important role in the Niagara Peninsula. A significant number of grape farms are located in Niagara-on-the-lake, St. Catherines, and Lincoln. The numbers of farms that have a large value of agricultural capital are significantly greater in Niagara-on-the-lake and Lincoln than St. Catherine (Figure 5).

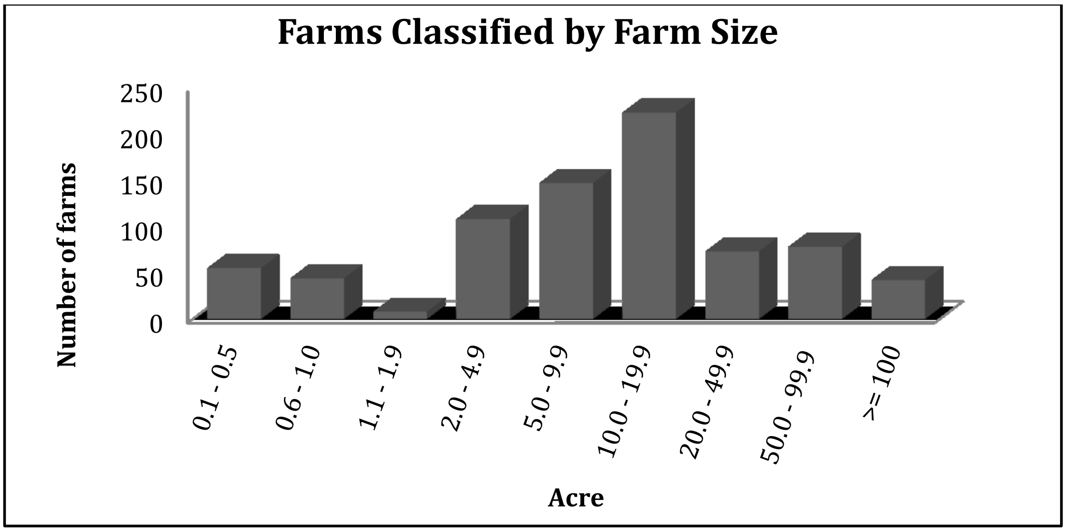
Figure 5: Farms Classified by Value of Agricultural Capital by Grape Area



Source: Data based from Statistics Canada, Census of Agriculture, 2011

Farm sizes of grape production in the Niagara Peninsula are given in Figure 6. The largest number of farms falls in the 10-19.9 acre range. The acreage farm size of grape production in the Niagara Peninsula is 26 acres. There are 42 farms equal to or greater than 100 acres.

Figure 6: Farms Classified by Farm Size



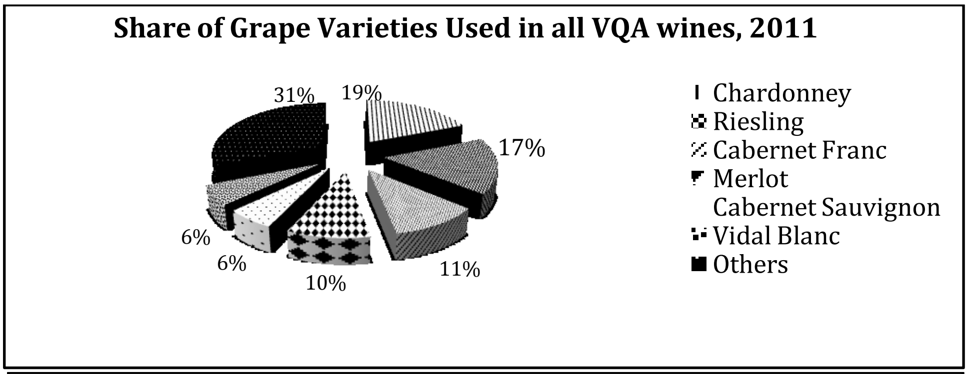
Source: Data based from "Grape Growers Ontario", Census of Agriculture

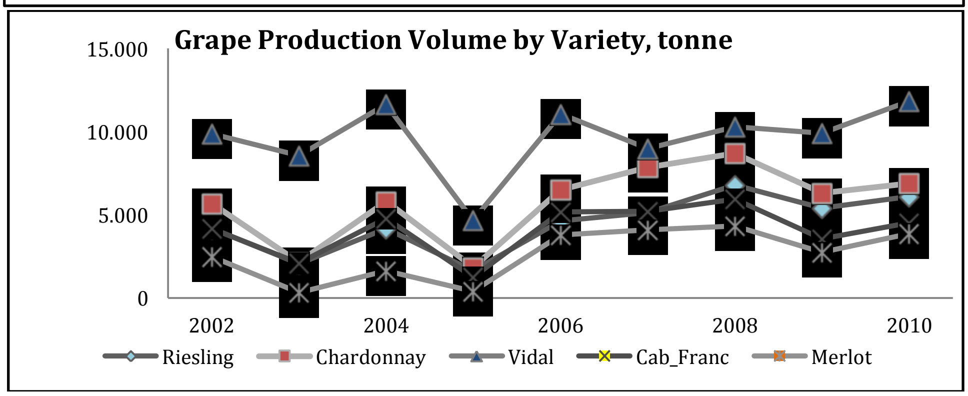
Grapes are the highest-ranked Ontario agricultural fruit commodity and represent 35% of the farm value of Ontario commercial fruit. Grapes can be used to produce wine, juice, or consumed as a fresh fruit. Fruit is the most dominant farm type in the Niagara Region in terms of numbers of farms (776 farms) among which grape produces represent the largest number (545 farms out of 776) (Regional Municipality of Niagara, 2010). The Niagara Region is known for its high quality grape production. The region currently produces 90% and 71% of the production of grapes in Ontario and Canada respectively (Grape Growers Ontario, 2010). The Niagara Peninsula is also one of the most important “cool varieties of grape” producing regions in the world. Climate change (hotter days) could be viewed as a threat to cool climate varieties’ that are produced in the Niagara Peninsula (Cyr et al., 2008).

There are two main grapevine grown in the Niagara Peninsula: *vinifera* and *hybrids*. In 2000, *vinifera* grape sales to wineries were $20.4 million, *hybrid* were valued at $18 million in 2010 (VQA, Ontario). Moreover, the world’s highest quality wine grapes belong to a species of grapes known as *Vitis vinifera* commonly referred to as *Vinifera*, which are native to Europe. The majority of vinifera grape varieties in Ontario are Chardonnay, Cabernet, Gamay, Merlot, Pinot Noir, Riesling (Shaw, 2005).

Soil, microclimate, and geographical characteristics play a key role in producing a good wine. However, the most important element of winemaking is the quality of the vines. In Ontario, there are more than 50 different varieties of wine grapes. The dominant varieties in production are from *V. vinifera.* In terms of their profitability, *Chardonnay* and *Riesling* are the most profitable white varieties and *Cabernet Franc* and *Merlot* are the most profitable red varieties and *Vidal* for icewine. Niagara Peninsula's wine category includes white, red and rose. White varieties' volume is greater than the red varieties. *Vitis vinifera* is the dominant variety used for grape production in the Niagara Peninsula since 1995 (Figure 7).

Figure 7: Selected Indicators of Grape Varieties for Ontario





Source: based on Grape Growers Ontario's databank

Maintaining competitiveness for the Ontario wine industry depends on how efficient Ontario's agricultural producers, especially grape growers, adapt to and prepare for future climate conditions. Grape production should investigate adopting management techniques and new technology that can address the potential adverse impacts of climate change. In addition, institutional mechanisms, such as insurance programs, can be used to address the adverse impacts of climate change.

CHAPTER 3

LITERATURE REVIEW

3.1. CLIMATE CHANGE AND AGRICULTURE

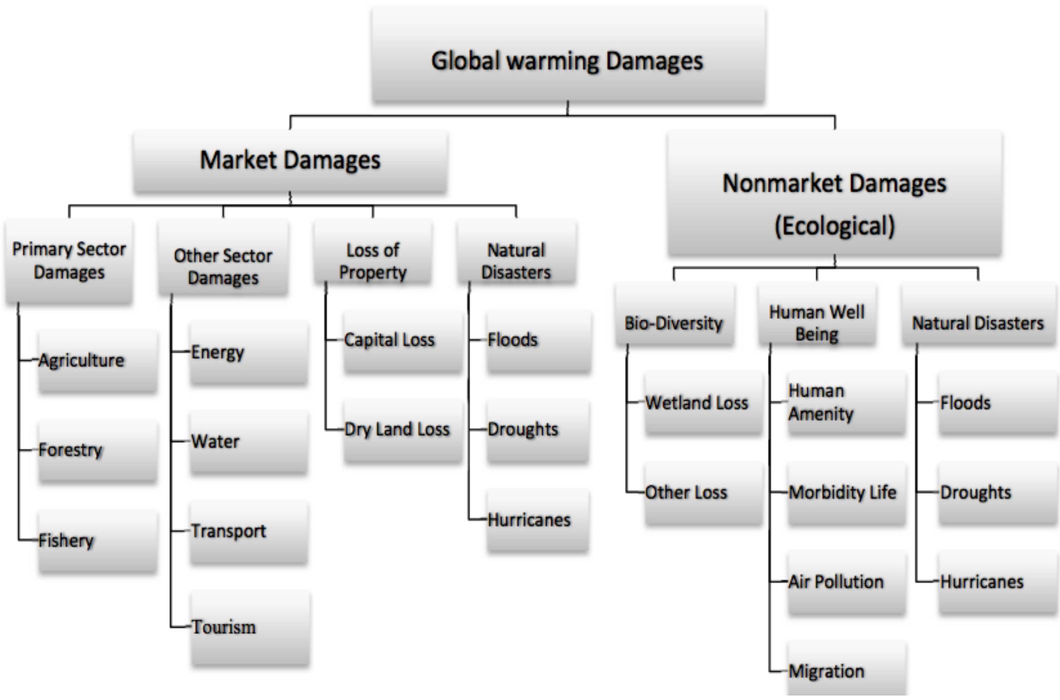
Scientific debates on global climate change still exist after more than thirty years. Recently, the IPCC in its fourth Assessment Report (AR4) stated that:

> "Observational evidence from all continents and most oceans shows that many natural systems are being affected by regional climate changes, particularly temperature increases... [and that the] magnitudes of impact can now be estimated more systematically for a range of possible increases in global average temperature..." (IPCC, 2007a; page 1 and page12)

Climate change impacts can be divided into two categories; market impacts and non-market damage (Figure 8) (Manne et al., 1995). The potential impact is greatest on the primary economic sectors such as agriculture, forestry, and fishery. This is because these sectors are highly sensitive to changing climate.

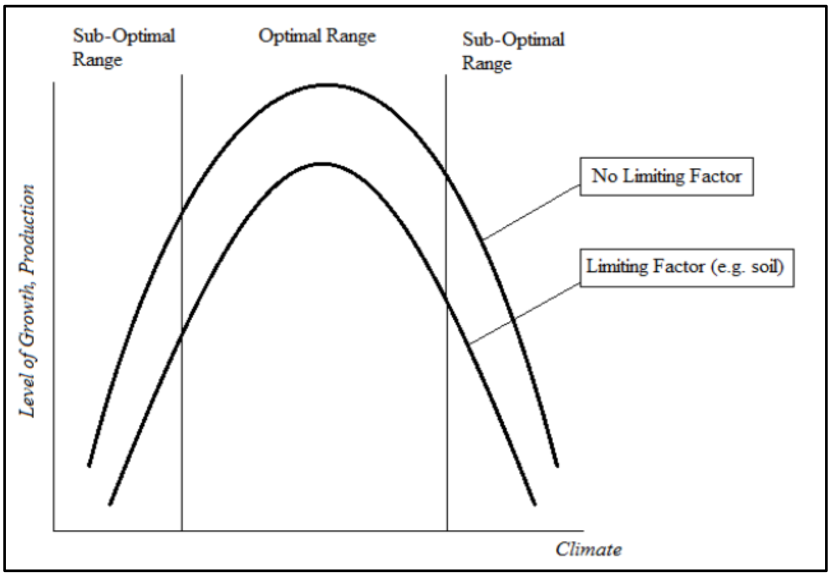
Climate change impacts on agriculture are expected to be different depending on crop type, geographic location, degree of warming, precipitation change, and changes in CO_2 levels (McCarl et al., 2001). The net effects of increased CO_2 will depend on local conditions (Rosenzweig and Hillel, 1995; Tubiello et al., 2002). There is also sufficient evidence to suggest that the existing optimal growth range of crop and livestock production correlate with temperature, precipitation, soil, and water (Figure 9).

Figure 8: Overview of Global Warming Impacts



Source: Manne, A. Mendelsohn, R., and Richels, R. 1995. "MERGE: A Model for Evaluating Regional and Global Effects of GHG Reduction Policies"

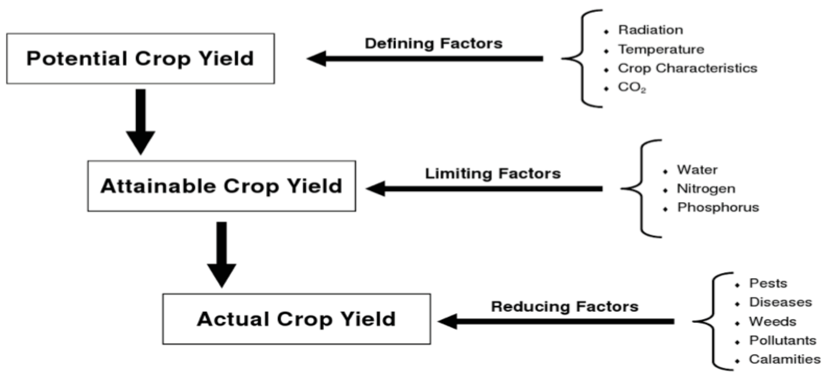
Figure 9: Climate and Soil Interaction on Growth and Production of Crops and Livestock



Source: Dinar, A. and Mendelsohn, R. (2009). Climate change and agriculture: An economic analysis of global impacts, adaptation and distributional effects. Northampton, MA: Edward Elgar Publishing, Inc.

Climate change and/or increasing levels CO_2 concentration can have direct and indirect effects on agriculture. The most important direct effects of climate change and increased CO_2 concentration on agricultural production are temperature and precipitation changes. The indirect effects on agriculture will be the emergence and distribution of crop pests and livestock diseases, weeds, pollutants, the frequency of adverse weather conditions, reducing water supplies and irrigation; and increasing severity of soil erosion and calamities (Figure 10) (Deschenes and Greenstone, 2006; Watson et al. 1998; IPCC, 2001).

Figure 10: Climate and Weather Factors Codetermine the Potential and Attainable Crop Yields



Source: based on Goudriaan and Zadoks, 1995

3.2. DIRECT IMPACTS OF CLIMATE CHANGE ON VITICULTURE

The impacts of climate change on wine industry are often reported because of the importance of this industry in many countries (Berger, 2007; McQuaid, 2011; Kakaviatos, 2006). The regions of Burgundy and Bordeaux in France are major wine-producing regions in the world. Chile is another wine producing and exporting country. The wine industry in Chili contributes significantly to the national economy with US $883 million export value in 2005 (Hadarits, 2009). England is another emerging wine producing country that produces sparkling wines with a comparable quality in Champagne, France (Jones, 2004).

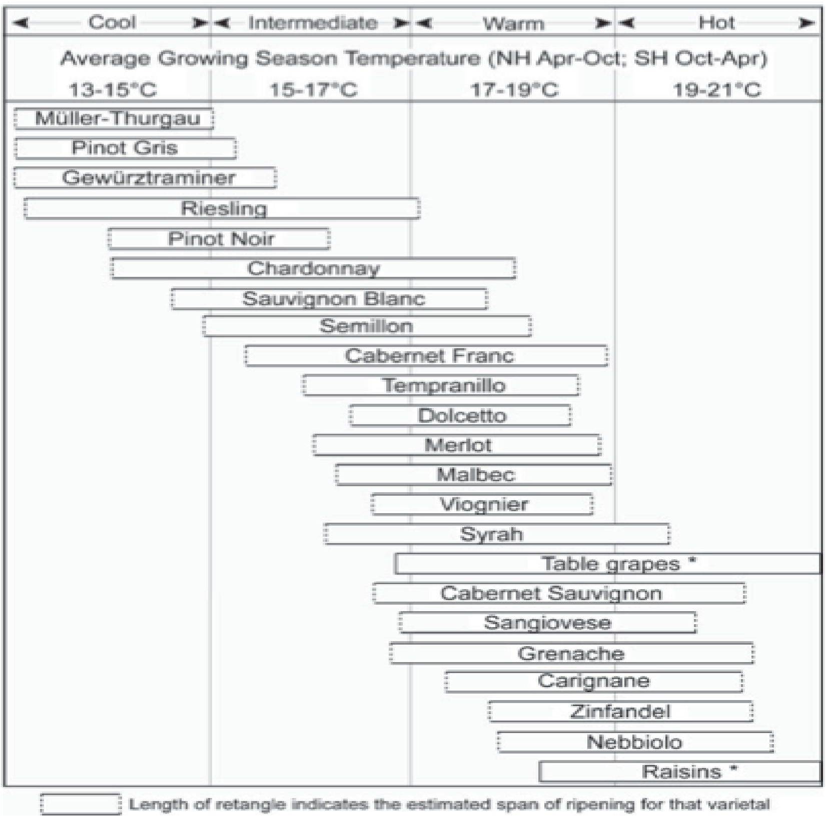
The viticulture industry is extremely sensitive to weather. Wine production worldwide depends on microclimates that provide the conditions needed to produce a quality product. The climate structure in a given wine-producing region largely determines the suitability of the region to different wine grape cultivars and the economic viability of the industry (Jones et al., 2012). The role of climate suitability in viticulture and wine production are now being studied because of the economic impact on the industry (Jones, 2004). Although there is common weather-related risks that grape growers face globally, the relative importance of these factors vary by region and grape variety (Cyr et al. 2008).

There are many case studies that examine the relationship between climate parameters; i.e. temperature, sunshine hours and seasonal rainfall distribution, and grape production; i.e. vegetative growth, fruitfulness, and composition of the fruits (Jackson and Lombard, 1993; Gladstones, 1992; Tonietto and Carbonneau, 2004; Jackson and Spurling, 1988; Shaw, 2012; Jackson and Spurling, 1988; Jones, 2007). The suitable wine regions are identified by the relationships between wine_grapes and climate for grape production.

To place the production of different wine varieties in the context of climate suitability, various temperature-based metrics; i.e. degree-days, mean temperature of the warmest month, average growing season temperatures, etc… can be used for establishing optimum regions (Gladstones, 1992). For example, the average growing season temperature typically defines the climate-maturity ripening potential for premium quality wine varieties (Jones, 2006). Each variety has a different genetically determined ripening profile (Kerridge and Antcliff, 1996). Some varieties ripen earlier in the season than others. The timing of the stages is driven by temperature then matching the suitability of a particular variety to the climate of a particular region is paramount (Figure 11[3]).

[3] The climate-maturity groupings given in this figure are based on relationships between phonological requirements and climate for high to premium quality wine production in the world's benchmark regions for each variety. The dashed line at the end of the bars indicates that some adjustments may occur as more data become available, but changes of more than +/- 0.2-0.6°C are highly unlikely.

Figure 11: Grapevine Climate/Maturity Grouping

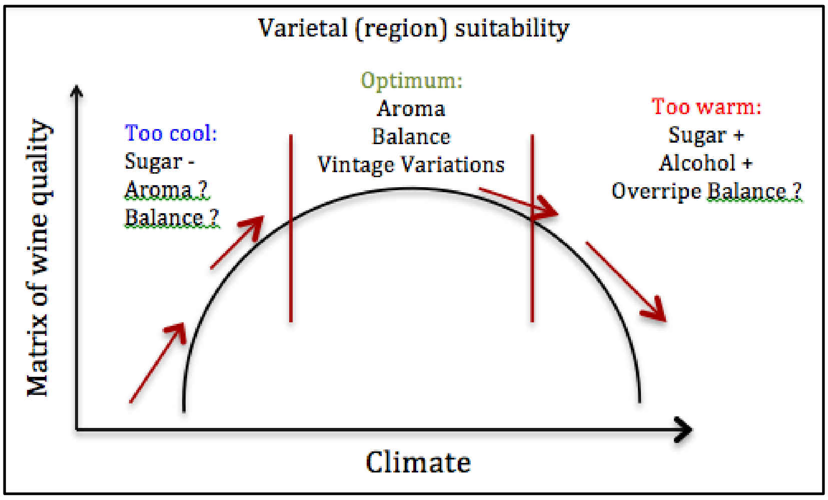


Source: Jones, G. V. 2006. Climate and terroir: Impacts of climate variability and change on wine. In Fine wine and terroir – the geoscience perspective, ed. R. W. Macqueen, and L. D. Meinert. Geoscience Canada Reprint Series Number 9, Geological Association of Canada, St. John's, Newfoundland.

Cabernet Sauvignon is grown in regions that span from intermediate to hot climates with growing seasons that range from 16.5-19.5^{0}C; for example in the Bordeaux Region or the Napa Valley. For cooler climate varieties, such as Pinot Noir, they are typically grown in regions that span from cool to lower intermediate climates with growing seasons that range from 14.0-16.0 ^{o}C; for example Northern Oregon or Burgundy. Early-ripening varieties, such as Riesling is typically grown in regions that span from cool to lower intermediate climates with growing seasons that range from roughly 13.0-17.0^{o}C (Jones, 2007); for example, Northern Oregon or Burgundy, (Jones, 2007); São Joaquim-SC in Brazil, (Gris et al., 2008); and the Niagara Peninsula, Canada (Jones, 2006).

Figure 12 illustrates how grape quality might vary with changes in climate. Boundaries of suitable climates for wine production to be the shape of an inverse “U” curve. The inverted U curve defines optimum temperatures for the production of quality wine. Above or below the optimum temperatures may increase/decrease quality of wine in some regions (Webb, 2006; Jones et al., 2005; Schultz, 2000).

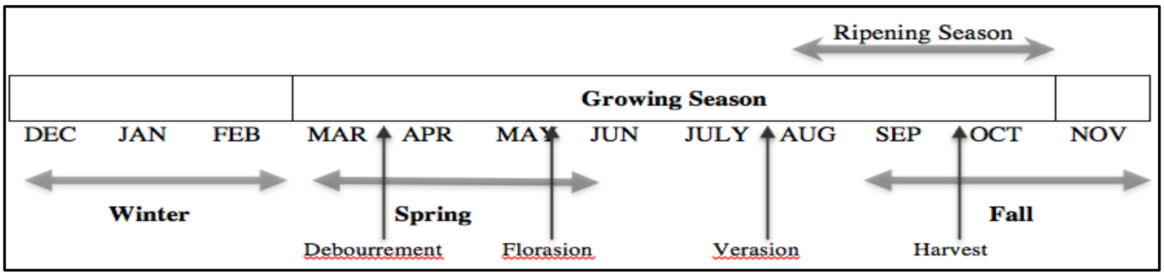
Figure 12: Varietal (region) suitability of climate



Source: Schultz, 2000

Vitis vinifera grapevines’ phenologically development stages are budburst, flowering, color change, maturation nascent, and grape maturity. Studies have demonstrated that there are some shifts in the grape phenological stages due to the direct effect of climate (Jones and Davis, 2000). For example, phonological shifts on quality for Merlot and Cabernet Sauvignon varieties in the Bordeaux region were observed. The increased berry composition with an increase in the number of warm days and the decreases in precipitation during maturation was analyzed (Tomasi et al., 2011). Another study in the Italian Conegliano region observed that for every 1°C degree increase in temperature during the phenological time generates earlier bud break (3 days), bloom (4 days), and harvest (8 days) (Tomasi et al., 2011). In California; climate change has seen an increase in unexpected negative factors such as disease outbreaks due to high humidity (Nemani et al., 2001). It is expected that a 1-2 month earlier ripening period will lead to reduced grape quality in California by the end of this century (Hayhoe et al. 2004). In light of these scientific findings, changing vinegrape phenology in the Niagara Peninsula might have important implications in the coming decades. Different varieties have different development stages as seen in Figure 13.

Figure 13: Overview of Wine Grape Development



Source: Jones and Davis, 2000

Impacts of climate change are not likely to be uniform across all varieties and regions, but are more likely to be related to climatic thresholds. Any continued warming would push a region outside the ability to produce quality wine with existing varieties. For example, if a region has an average growing season temperature of 15°C and the climate warms by 1°C, then that region becomes climatically more favorable for ripening some varieties (Jones, 2012).

Climate change effects are not only on winegrape phenology, but also on yield and quality. There is a positive relationship between increasing temperature in terms of sunshine and crop yields. On the other hand, there is a negative correlation between grape quality with reducing rainfall in the beginning of the growing season, or increasing rainfall in the last months of the season (Jones and Storchmann, 2001; Grifoni et al., 2006; Chloupek et al., 2004). However, climate change will affect grape yields and wine qualities either positively or negatively due to the nonlinear correlation between the climate parameters (Jones et al., 2005; Lobell et al., 2006).

A warmer growing season can improve wine quality with earlier phenological timing, but decrease yields due to a combination of water shortage and heat stress (Ramos et al., 2008; Jones and Davis, 2000). These wines can be unbalanced with high sugar content, resulting in high alcohol, lower acidity, too high pH, and compromised flavor profiles.

Precipitation and temperature values are critical during the growing season for some viticultural regions which have rain-fed or cool climates, for example, the Niagara Peninsula. In the Niagara Peninsula the precipitation should be below 700 to 800 mm and above -2 ^{0}C at the bud burst stage, respectively (Jackson and Schuster, 1987; Shaw, 2005). Without any moisture stress to the vine, warm and dry growing seasons are also correlated with good quality grapes and high prices (Haeger and Storchmann, 2006). Therefore, the hypothesis “warmer is better” may not be correct for all grape growing regions (Jones, 2006).

It is a common consensus that rising carbon dioxide (CO_2) concentrations lead to increased grape yield and water use efficiency due to enhanced photosynthesis (Bindi et al., 2001; Bazzaz, 1990; Schultz, 2000). More comprehensive studies predict yield decreases due to increased temperature and changes in solar radiation since grapevine yield is more sensitive to CO_2 concentration and temperature than solar radiation levels (Bindi et al., 1996). Unlike direct positive effects of elevated CO_2 on winegrape yield, indirect effects of CO_2 may not be beneficial for grape yield. Because they could result in elevated humidity, which can increase winegrape diseases (Nemani et al., 2001).

3.3. INDIRECT IMPACTS OF CLIMATE CHANGE ON VITICULTURE

3.3.1. Soil and Water Effects

Soil characteristics influence yield and quality and in some cases can largely define a region. Elevated CO_2 concentration impacts viticultural soil patterns. Changing soil patterns has an impact on vine balance (reproduction of vine), optimum fruit quality, and yield. There are non-linear effects of climate change caused by interactions between soil, climate and nutrition. These interactions increase the aridity and often result in a decline in soil structure and increased salinity (Dry et al., 2005; Clark et al., 2002; Richards et al., 2008). Changing temperature patterns also influences soil characteristics and generates pest and disease pressure on vinegrape depending upon the growing region. For example, Pierce's disease[4] is predicted to move to Oregon and Washington wine regions where it is currently not present due to lower winter temperatures - (Tate, 2001; Salinari et al., 2006). There is an increased risk of phylloxera insects on vinegrape that are spread after drought events when water allocation to vines is reduced due to extreme warming (Anderson et al., 2008).

Water is another aspect of climate that affects grapevines. Rainfall will affect a grapevine's supply of water directly by falling on the vineyard and indirectly

[4] Pierce's Disease is a deadly disease for grapevines. It is caused by the bacterium Xylella fastidiosa, which is spread by xylem feeding leafhoppers. Pierce's Disease is known within the USA from Florida to California, and in Central and South America. Xylella fastidiosa works by blocking the conduction the water around the plant. It effects the entire vines which die after 1-5 years. Pierce's Disease is less prevalent where winter temperatures are cold, such as more northern areas, high altitudes and inland areas (http://www.piercesdisease.org/)

through irrigation water availability from rivers, dams and underground sources. The difference between rainfall and evaporation (aridity) will impact the vines' demand for water (McCarthy et al. 1992). Rainfall and humidity also affect growth of many fungal disease pathogens that affect grapevines (Magarey et al. 1994).

3.3.2. Wind and Humidity Effects

Some level of humidity is required to acquire a balanced potassium content in grapes. Excess potassium leads to the loss of tartaric acid and a lower sugar-to-acid balance in grapes. Excess humidity leads to fungal diseases especially at higher temperatures. Excess humidity is usually associated with too much rain and lack of sunshine. Early afternoon relative humidity between 50 and 60 percent through the summer and ripening period would appear to be ideal for winegrapes grown in cool to mild climates, while a range of 40 to 50 percent relative humidity is ideal for warmer climates (Gladstones, 1992).

Wind has both positive and negative effects on vines. Moderate wind circulates the air and prevents excess humidity in the vine canopy. Wind also helps to maintain moderate temperatures in and around the vine, reducing potential frost damage as well as exposing the shaded vine parts to the sun. Strong winds in spring or early summer will injure growth of bunches. Hot, dry winds especially at the beginning of the veraison stage can cause collapse of exposed berries and imperfect ripening of berries that survive. Moderate wind can cause closure of stomata in the leaves and thus slow down photosynthesis and ripening (Gladstones, 1992).

3.4. ECONOMIC IMPACTS OF CLIMATE CHANGE

The physical effects of climate change do not tell the whole story. Changes in agricultural supply may be influenced by the combination of changes in yields and changes in crop acreage size and location, changes in human consumption patterns, international trade adjustments and many other factors (McCarl et al., 2001). Vineyard costs vary for land, labor, machinery, and materials in different grape growing regions due to geographic conditions even if climate change is ignored. Numerous economic studies indicate that increasing the frequency of extreme meteorological events impact total acreage, prices, grape cultivar, vine spacing, training system, cropping patterns and management practice (Adams et al., 1995; Shapiro et al., 2007; McCarl et al., 2001; Bordelon, n.d.). A recent study that focused on Australia winegrape growing conditions regionally and nationally, found that with no adaptation or change in production, winegrape quality, measured by average price, may be reduced between 7 and 39 percent by 2030, and by 9 to 76 percent by 2050, depending on the type of warming (Webb et al., 2008). Furthermore, a change in productivity from climate change will be harmful to producers and/or consumers and would thereby suffer economic losses.

Results from marginal analyses confirm that production margin will be sensitive to climatic change and variability (Reilly et al., 2000).

Moreover, the main cost of climate change is associated with increases in temperature and pests in vineyards. Economic analysis on the cost of pest, disease, and bird control and production losses confirms that diseases are the largest problem and costs in growing grapes. Insect pests affect production costs and crop loss in grape growing regions and these effects will increase with increasing temperatures (Nicholas et al., 2007; Sutherst, 2000; Thomson and Hoffman, 2010).

Climate change is often viewed as a shift of climatic zones and related agricultural activities to higher elevations (UNEP, 1999; Zilberman, 2001). The ecosystem modification paradigm relies on changes in the composition and dominance of species, "*the ecosystem movement paradigm assumes that ecosystems will migrate relatively intact to new locations that are closer analogues to their current climate and environment" (*Gitay et al., 2001, p.248). Under this paradigm, producers who are closer to the poles could become better off than those closer to the equator (Zilberman et al., 2004). In the northern areas, production could increase due to an expansion of viticultural land and an increase in yields which result from the CO_2 fertilization effect. According to this new situation, Canada might have an advantage for larger viticulture areas. Global warming could radically change the global wine industry as temperatures increase. For example, the lucrative UK market could disappear due to an increase in sales of locally produced British wines. Germany might abandon the Riesling grape and plant more profitable Shiraz or Chardonnay, and the cooler wine regions of France could produce consistently good vintages year after year. Hence, patterns of trade in wine and other related agricultural commodities at national and international levels could be altered (McCarl et al., 2001; Vickers, 2011; Addor and Grazioli, 2002).

Climate change may provide economic opportunities for the production of warm climate wines in the Niagara Peninsula. As a result, farmers may find themselves more exposed to problems for cool climate grapes in a wine market, which would be brought about by higher prices of white grapes. Also, while many crops are adapted to a growing-season day-length of the middle and lower latitudes, they may not respond well to longer days of the high latitude summers. This difference might also result in negative cash flows for farmers (Rosenzweig and Hillel, 1995; Penney et al., 2012).

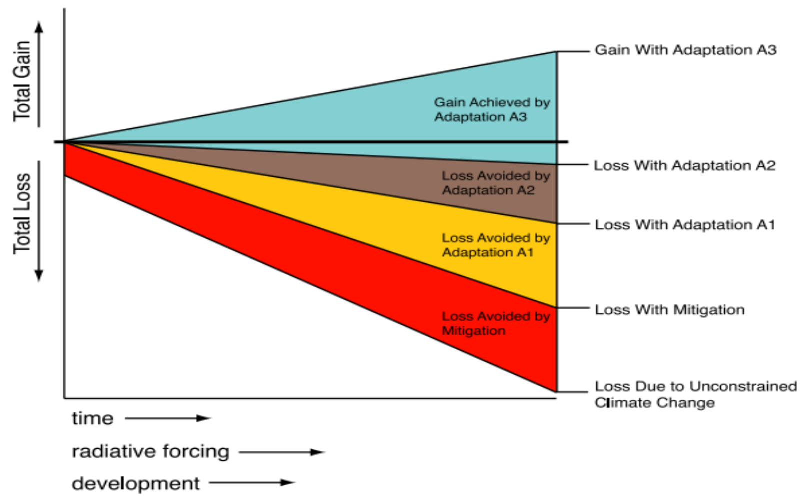
Some of the simulation results indicate that grape varieties would shift due to the potential reduction of their production and yields with a warmer climate. For example, Shiraz and Chardonnay showed a reduction in a suitable area of between 10-15% and 40-60% respectively in Australia by 2050s (Webb et al., 2008; Paterson, 2004). A similar reduction in Chardonnay, which is one of the most produced varieties, might also be observed in the Niagara Peninsula. However, in the short-run, the shifts may not be technically or economically efficient in many regions with given current socio-economic conditions.

There are several factors that affect a vineyard's quality and the grapes it produced. For example, there is a clear interrelation between solar radiation and temperature for projected changes in climate scenarios. This relationship affects producer's profit because the quality of the grape impacts the price that the producer receives. Ashenfelter and Storchmann (2010) estimated a 1◦C increase in temperature would increase a producer's revenue by approximately 30% in the short run.

3.4. ADAPTATION AND MITIGATION STRATEGIES IN VITICULTURE

Adaptation processes play a major role in reducing climate change impacts on agriculture. Examples of adaptation processes in viticulture are irrigation and nitrogen management techniques (Easterling et al, 1992; Mendelsohn et al, 1994; Bryant et al, 2000; Smit and Skinner, 2002). There are two main issues for adaptation to climate change (Smit and Skinner, 2002). First adaptation reduces the impact of climate change (Tol et al, 1998) and the second adaptation strategies become incorporated into policy options (Fankhauser, 1996). Implementation of effective adaptation activities requires quantification and sensitivity of the possible impacts of climate change to different adaptation activities. Diffenbaugh et al (2011) have recently developed a novel method for communicating potential climate change impacts for the wine industry using climate adaptation "*wedges*". According to their method, the damage avoided by each activity creates a wedge relative to the loss that would occur without that activity (Figure 14). These wedges are similar to the GHG stabilization wedges of Pacala and Socolow (2004), and aggregate the total benefit relative to non-adapted impacts. Hence, the net gain or loss in wine production under a range of adaptation strategies is identified.

Figure 4: Conceptual illustration of the climate adaptation wedges framework



Source: Diffenbaugh, et all., 2011

The growing concern of climate change for the global wine-industry has resulted in an emphasis on adaptation to this change (White et al., 2006, 2009; Hertsgaard, 2011). Producers will have to adapt to climate change for the sustainability of their sector. Furthermore, while adaptation options have been identified for some agricultural sectors, vineyards might be less flexible to adaptation as grapes are perennial crops. Studies conducted over multiple years are critical to enabling development of future adaptation strategies and to test cultivar suitability in a changing climate. Growers will require knowledge to choose from among alternative options to prepare for warmer growing seasons with less water and, in some areas, increasingly saline soils (Keller, 2007). There are few options to adapt to new climate conditions. Changing grape varieties in response to climate is one option; however, new crops could be unsuited to soil conditions (Hertsgaard, 2011; Ashenfelter and Storchmann, 2010). Therefore, instead of switching crops, modifying vineyard management to the changing climate will play an important role in the adaptation of the winegrape industry (Diffenbaugh et al., 2011; Webb et al., 2011). Other options for adaptation to changing climate may include traditional measures such as changing the trellis system, changing the pruning regime, row orientation, irrigation techniques (Gatto et al. 2009; White et al 2009; Diffenbaugh et al., 2011), and vine rootstock selection (Webb et al., 2012). Another important way for climate change adaptation is soil management. Soil management will have to take its place alongside canopy management as a key component of the sustainable vineyard management ‘toolbox’ (Keller, 2005). This calls for research into the integration of vineyard floor management to optimize vine productivity, maximize fruit quality and ensure long-term soil fertility (Morlat and Chaussod, 2008). The last option is to use genetically modified cultivars of the V. vinifera genome that will be able not to cope with warmer temperature, higher CO_2 and less water and higher salinity, but will also produce high-quality fruit under such conditions (Webb et al. 2011).

Climate change impact assessment not only includes changes in average temperature or precipitation but also the magnitude and frequency of extreme events which are particularly problematic for agriculture (Brklacich and Smit, 1992; Smithers and Smit, 1997; Klein and MacIver, 1999). A recent report raised concerns that the projected increase in the frequency of hot summer days might eliminate wine grape production in warm areas of the USA, and production would shift to cooler areas (White et al. 2006). It has been estimated that 80% of production in Southern Ontario will be affected by extreme climate problems, such as moisture (Chiotti et al., 1997)

Sun-exposed grape berries that are subject to sunburn could resulted the effect of overheating and excess UV. The projected increase in the frequency of hot summer days will exacerbate this sunburn problem, especially on the afternoon side of canopies[5] (Keller, 2010). This may require adaptations in a row direction, or using wind turbines.

[5] Afternoon side of canopies receiving afternoon sunlight will reduce the incidence of sunburn on fruit in hot climates

The wine sector will not only be affected by climate change, but also by changes in consumer preferences. Changing grape varieties as an adaptation option could be inefficient if consumers do not accept the new grape varieties (Metzger, 2011). Some regions, such as Burgundy, are likely to be adversely affected by climate change since most of the red grape varieties are sensitive to climate (White et al., 2009). Scenario analysis (Rounsevell and Metzger, 2010) and the exploration of climate adaptation wedges (Diffenbaugh et al., 2011) will be important tools to help the planning of winegrape production in the uncertain future.

CHAPTER 4

RESEARCH DESIGN AND METHOD

4.1. DETERMINING METHODOLOGIES TO THE IMPACTS OF CLIMATE CHANGE ON AGRICULTURAL CROPS

Various studies have used different methods to investigate the effects of climate change on agricultural production. These methods have addressed the climate change impact on agriculture in different ways; for example changing production or plant growth (Singh and Stewart, 1991; Kenny et al., 1995); new farming practices, global food production; and economics (Easterling et al., 1992; Parry et al., 2004; Kabubo-Mariara and Karanja, 2007; Ortiz et al., 2008). However, there are two models in the literature which are widely accepted to demonstrate the impacts of climate change on agriculture. These are 'plant process-based' models and 'statistical empirical models' (Iglesias et al., 2000).

4.1.1 Plant Process-Based Models

Decision Support Systems for Agro-Technology (DSSAT), Agricultural Production Systems Simulator (APSIM), Crop Environment Resource Synthesis (CERES), CropWat, Cropping Systems Simulation Model (CropSyst), Erosion Productivity Impact Calculator (EPIC), and Vine Development Simulator (VineLogic) are some of the plant process-based models. These models focus on how a specific plant responds to changing environmental factors, such as weather, soil, carbon as well as management practices within a given time frame. Some of these models run with predicted climate change scenarios using IPCC data as they are used for future climate change impacts on agricultural crops.

Plant process-based models have different options to integrate various factors such as environment, nutrition and management practices' options to estimate the impacts of climate change on various crops; for example maize (Tubiello et al., 2002), rice (Yao et al., 2007), and winegrapes (Webb et al., 2008). These models have been developed to take into account specific regions but were found to be useful and applied successfully to other studies.

4.1.2 Statistical Approaches/ Empirical Models

The statistical models estimate the relationship between certain climate factors and corresponding variations in crop features. The projection of climate variables drives the statistical models to simulate plant growth under various climate scenarios. Many researchers have used this approach to estimate the impact of climate change on agriculture for example; wheat yield (Landau et al., 2000), yields of dominant crops in California (Lobell et al., 2006); grape yield in California (Lobell et al., 2007); Icewine derivatives (Cyr and Kusy, 2007), the effect of climate variables during different stages of grape growth in British Columbia (Caprio and Quamme, 2002), and wine market prices in France (Jones and Storchmann, 2001).

Unlike plant-based models, statistical models do not include physiological processes of plant growth. In these models, the relationship between yield and the climate variables can be used to predict future climate impacts on crop yield. However, these models cannot be used to predict crop yields when alternative management practices attempt to mitigate the impact of climate change (Levin and Muller-Landau, 2000). The statistical approach is frequently used to demonstrate how climate variability impacts vine growth and quality on different elevations in same viticultural region (Jones and Davis 2000; Nemani et al. 2001; Jones et al. 2005; Sadras et al. 2008).

4.2. INVESTMENT DECISIONS METHODS FOR PERENNIAL CROPS

4.2.1. Net Present Value

Jefferson-Moore et al. (2008) developed a discrete time period model with multi-period horizons by using the Net Present Value (NPV) analysis for the wealth maximization of wine, wine grape, and/or grape juice producers in State of New York, US. Key (1982) conducted a study involving the profitability of investing in the grape industry utilizing the NPV analysis to evaluate vineyard and winery investments. The initial outlay amount is applied into the Faustmann method[6] of NPV in their model. If the NPV is greater than or equal to zero, then the investment may be accepted or vice versa. The difficulty of this procedure was the inability to yield consistent rankings of mutually exclusive investments relative to NPV rankings. Therefore, the discount rate (also assumed to be the reinvestment rate) that equates present and future values of the proposed investment is important. It can be referred to as the Modified Internal Rate-of-Return (MIRR) or a Marginal Return on Invested Capital. The MIRR finds the present value of the cash *outflows (CO*), and the future value of net cash inflows (CI), and modified internal rate of return. This study assumes that the required rate of return is equivalent to the total cost of capital for the investor. Therefore, if the MIRR exceeds the required rate of return (the opportunity cost of capital), then it is recommended that the investor/farmer accepts the investment or *vice versa*.

Khair et al. (2009) has used the methodology of ex-post analysis to evaluate the cost and return of long-term investment decisions for grape production in the Pishin district, Pakistan. This ex-post analysis offers the true worth of farmer's long term investment decisions for grape production. The first few years of grapes involve only costs, so that the flow of future costs and returns

[6] Faustmann is forestry economics and he introduced firstly "when should farmers harvest and when should they replant?" in NPV analysis: where C is replanting cost, i is discount rate, T is harvested age and G(T) is the value of stumpage harvested at age T. This Faustmann rule has been applied not only in defining the optimal harvest age, where the yield is determined at the end of the economic life of the tree, but also in examining the investment decision of perennial crops where they are continues flows of benefits (Bauer et al., 1990).

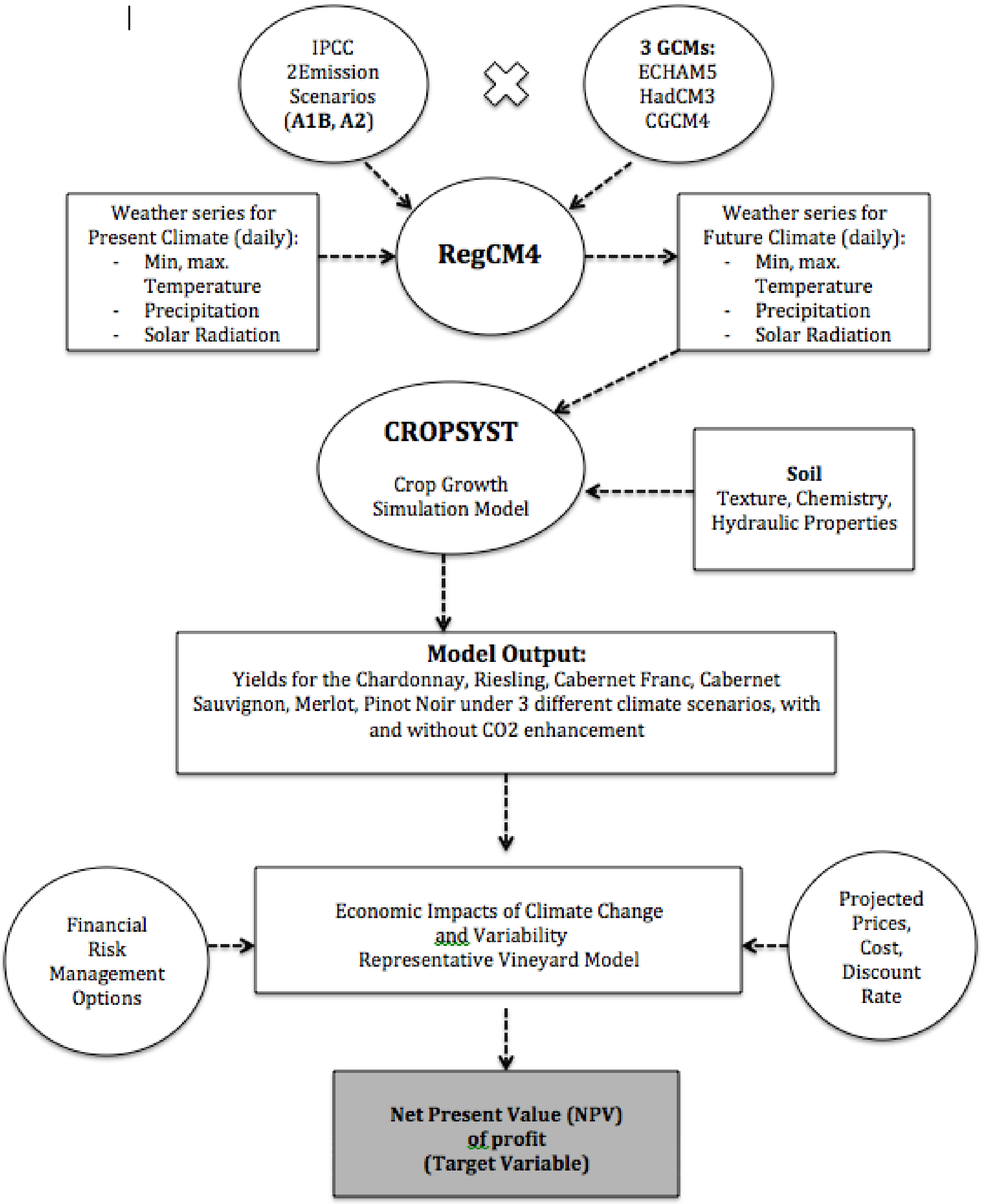
are also important. A basic approach is to estimate the annual net present worth by discounting both future costs and returns for farm management. Therefore, three techniques – Net Present Value (NPV), Internal Rate of Return (IRR), and Modified Internal Rate of Return (MIRR) - considering the time value of money over the life of grape investment were used (Khair et al., 2009).

4.3. MATERIAL AND METHOD

An integrated bio-economic modeling approach (IBEM) is used to link the process-based crop growth model CropSyst with an economic model. Figure 15 below shows the structure of the bio-economic modeling approach as mentioned earlier. The IBEM set-up consists of three sub-models: the Spatial climate model, the crop growth model CropSyst, the economic decision model to calculate Net Present Value of the representative vineyard. The IBEM was generated by using predetermined parameters, climate and soil data, and information from growers in the study area, such as management practices, cultivar, planting and harvesting date, adaptation decisions due to the climate conditions. The future yield simulations were estimated using CropSyst, an agronomic model, based on variables from different climate scenarios. Prices and costs of production were projected into the future. Insurance coverage options were also integrated into the net present value analysis over the 30 year period for the economic impact analysis. The acreage planted for each of

6 winegrape varieties at the start of the period and it was determined exogenously. Given this, the economic impact analysis estimated the net present value of a representative vineyard in the Niagara Peninsula.

Figure 15: Structure of the Bio-Economic modeling approach



4.3.1. Representative Vineyard

The representative vineyard is assumed to be 100 acres. Land is allocated to six grape varieties, chardonnay, riesling, cabernet franc, cabernet sauvignon, merlot, pinot noir, with respectively 19%, 26%, 16%, 10%, 9%, 20% coverage of the total area. The allocation was not changed over the 30-year planning horizon.

4.3.2. Climate Models

Regional Climate Models (RCMs) capture the geographical variation of temperature and precipitation better than Global Climate Models (GCMs) (Jacob et al., 2007; Lenderink et al., 2007). The regional model used in this research were derived from three global climate models which provide 1°x1° resolution. The regional derivation has a higher resolution at 2.5°x2.5° which provide many detailed results. These global climate models differ in spatial resolution, in scenarios availability and ability to represent the current climate. The Max Planck Institute climate model version 5 (ECHAM5), the Hadley Centre climate model version 3 (HadCM3) and the Canadian General Circulation model version 3 (CGCM3) were the three global climate models used. The Regional Climate Model (Giorgi et al. 1993a, b) of the Abdus Salam International Center for Theoretical Physics (ICTP), RegCM version 4.0 with the community land model (CLM) (Oleson et al. 2007) option was used to generate the climate change data for the IPCC Third Assessment Report (Hulme et al 2000; Wigley and Raper, 2002; Wigley 2003). Table 2 shows the characteristics of these models for the Niagara Peninsula. Two emissions scenarios from a Special Report for Emission Scenarios (SRES 2000) (with

CO_2 and without CO_2) (IPCC 2000) A1B and A2 were derived from the Global Climate Models runs. A1B was used with ECHAM5 (Median) and CGCM3 (Cold/Humid), and A2 was used with HadCM3 (Warm/Dry) for Niagara Peninsula. The A2 emission scenario is based on a population projection of 15.1 billion by 2100 and a concentration of CO_2 of 635–856 ppm, while the A1B emission scenario is median based with population projection of 12.4 billion by 2100 and 600–700 ppm by 2100 (IPCC, 2000). Using the emissions scenarios, a "best" and "worst" case summary can be synthesized in order to assess the viability and suitability of grape cultivation in the Niagara Peninsula.

Table 2: Characteristics of Climate Change Scenarios with GCMs for the Niagara Peninsula

	Regional Characteristic
Median	Middle emissions path modeled, Characterized by technological change with more balanced energy source, Slowing human population growth, Rapid economic growth, Temperature and precipitation increase in both Winter and Summer (between others)
Hot/Dry	Emphasized regional autonomy and sustained human population growth, Fragmented economic development, Higher summer temperature, Temperature increase in winter season (less than others), Precipitation decrease in summer and increase in winter
Cold/Humid	Middle emission path modeled, Precipitation increase in summer and decrease in winter, Temperature increase in winter, decrease in summer.

Source: Generated by the Author

The Niagara Peninsula is a small area under the domain of a horizontal resolution of 50 km. ECHAM5, HadCM3, and CGCM3 global climate model data sets, with a resolution of 2.5° x 2.5°, were used to obtain the initial and boundary conditions for the present climate period (1970-2000). RegCM4 simulated minimum, maximum, precipitation and solar radiation data for the future climate scenarios (2015-2044). The climate data was run by the Bogazici University Climate Change Project using the Atmospheric Ocean General Circulation Model (AOGCM).

4.3.3. CROPSYST and Yield Data

The Cropping System Simulation Model (CropSyst - version 4.13.09) was used to estimate future grape yields from the different climate scenarios and CO_2 concentrations. It is a process-based, multi-crop, multi-year cropping simulation model, which simulates biological and environmental processes on a single land block fragment on a daily basis (Stöckle et al., 2003). CropSyst allows for a simulation of a wide range of management options including crop rotations, cultivar selection, irrigation, nitrogen fertilization, tillage operations and residue management. CropSyst includes a wide range of crops, covering cereals, tubers and perennials. In CropSyst, processes are simulated in response to weather, soil characteristics, crop characteristics, and management options. The model is suitable for analyzing the impact of environment and management decisions on crop productivity, and has been tested for a wide range of environmental conditions (Donatelli et al., 1997; Stöckle et al., 2003).

4.3.2.1. Climate Data

4.3.2.1.1. Observed Weather Data

Minimum and maximum temperature and precipitation parameters were taken from detailed climate data collected by Environment Canada, from the "Welland" weather station over the period 1970-2000. Table 3 and Table 4 provide average annual weather information and monthly temperature and precipitation information for the Welland weather station. The station was strategically selected to provide a representative sample of the main climate data necessary to generate the various projections needed for the analyses. However, solar radiation data were not recorded by Environment Canada for the Welland station. As a result, the Welland station's latitude, longitude and elevation coordinates were used to estimate the solar radiation data from information provided by the NASA Climatology Resource for Agroclimatology Daily Averaged Data. Historical weather data were used to calibrate the CropSyst model for grape production in Niagara Peninsula.

Table 3: Characteristics of the Welland Weather Station

Station	Welland		
Station code	6139445	Annual Average	
Latitude	42°59'	Min Temperature (0C)	5.5
Longtitude	79°15'	Max. Temperature	14.8
Elevation	175.3	Precipitation (mm)	100.5

Source: Environment Canada - Canadian Climate Normals 1971-2000

Table 4: Monthly Temperature and Precipitation Regimes: Mean and Standard Deviation values correspond to observe weather data (Welland Station)

	Temperature		Precipitation	
	Mean	St. Dev.	Mean	St. Dev.
JAN	0.9	1.60	0.7	0.58
FEB	1.9	1.72	1.2	1.64
MAR	4.5	2.49	2.4	3.08
APR	9.2	1.82	5.9	4.36
MAY	14.6	1.82	21.0	9.44
JUN	19.9	1.51	33.9	15.54
JUL	22.5	1.09	36.8	21.06
AUG	21.4	1.41	32.7	16.78
SEP	18.4	1.33	21.7	12.12
OCT	12.6	1.50	9.7	6.31
NOV	7.0	1.46	3.1	1.75
DEC	3.0	1.76	1.4	1.92
Growing Season (APR-OCT)	16.9	4.95	23.0	12.11

Source: Generated by the author using data from Environment Canada

4.3.2.1.2. Synthetic Base Climate

The ClimGen weather generator software version 4.1.05 (Stöckle et al., 1999; 2001) was used to generate a synthetic daily weather series from daily data. ClimGen has been tested in many different locations (Villalobos et al., 1999; Castellvi and Stöckle 2001; Jovanovic et al., 2003). ClimGen uses a normal distribution to generate daily maximum and minimum temperature values. ClimGen generated the precipitation, daily maximum and minimum temperature, and solar radiation. All generated parameters were calculated for Niagara with enough information to parameterize the generator equations. The average and standard deviation of daily data for the Welland weather station were used as inputs into the ClimGen generation. Average and standard deviation of maximum and minimum temperatures were also calculated manually for the location. Future yield estimates in CropSyst were generated using synthetic weather data for daily minimum and maximum temperature, precipitation and daily total solar radiation. For the future period 2015-2044, the average change in the mean temperature for the Cold/Humid, Median, and Warm/Dry scenarios were plus 1.02^{o}C, 1.56°C and 2.13^{o}C respectively. The corresponding changes in total precipitation were increases of 13%, 7% and 5% respectively in the Niagara Peninsula. Table 5 shows comparison of the three different climate scenarios with the baseline scenario's monthly mean and standard deviation for temperature and precipitation. The growing season in the region for winegrape was from April to October. Temperature and Precipitation values are deterministic factors for wine grape quality. During the growing season temperature would increase from 16.9 ^{o}C (baseline) to 17.1^{o}C for the Median scenario, 18.0^{o}C for the Warm/Dry scenario, and 16.9^{o}C for the Cold/Humid scenarios. The precipitation would not change the baseline for the Median scenario whereas it would increase slightly with the Warm/Dry scenario from 23.09mm to 23.10 mm. In the Cold/Humid scenario, on the other hand, it would be from 23.09mm to 23.13mm.

Table 5: Monthly Mean and St. Dev. of Temperature and Precipitation for The Baseline (1971-2000) and Climate Scenarios (2015-2044)

Month	Scenario							
	BASELINE		Median		Warm/Dry		Cold/Humid	
	Mean	St. Dev	Mean	St. Dev	Mean	St. Dev	Mean	St. Dev
Comparison of projected value of temperature ºC								
JAN	0.9	1.60	1.5	2.01	2.6	2.00	0.6	2.05
FEB	1.9	1.72	3.3	2.33	4.4	2.32	2.4	2.22
MAR	4.5	2.49	5.1	1.76	6.1	1.75	4.1	1.65
APR	9.2	1.82	10.8	1.91	11.8	1.88	9.8	1.78
MAY	14.6	1.82	15.5	1.59	16.5	1.58	14.5	1.48
JUN	19.9	1.51	21.0	1.08	21.9	1.07	19.9	1.17
JUL	22.5	1.09	23.9	1.14	24.8	1.13	22.8	1.19
AUG	21.4	1.41	23.0	1.23	24.0	1.21	22.0	1.22
SEP	18.4	1.33	19.6	1.23	20.6	1.22	18.6	1.25
OCT	12.6	1.50	14.6	1.26	15.7	1.24	13.7	1.44
NOV	7.0	1.46	8.1	1.92	9.3	1.89	7.3	1.69
DEC	3.0	1.76	3.8	1.48	4.9	1.49	2.9	1.59
Growing Season (APR-OCT)	16.93	4.95	17.12	4.93	18.02	5.05	16.95	5.21
Comparison of projected value of precipitation mm								
JAN	0.7	0.58	1.5	1.71	1.3	1.46	2.0	1.71
FEB	1.2	1.64	2.0	2.52	1.7	2.18	2.6	3.02
MAR	2.4	3.08	3.7	3.12	3.2	2.65	4.5	3.39
APR	5.9	4.36	10.1	7.20	8.7	6.24	11.4	7.70
MAY	21.0	9.44	22.7	12.32	19.5	10.51	26.3	14.03
JUN	33.9	15.54	40.7	20.09	34.4	16.36	45.4	21.30
JUL	36.8	21.06	44.5	17.51	39.4	16.65	48.8	18.38
AUG	32.7	16.78	34.0	15.15	29.2	12.85	37.4	16.40
SEP	21.7	12.12	20.2	11.47	17.6	10.00	22.9	12.26
OCT	9.7	6.31	8.9	6.79	7.7	5.35	10.5	7.61
NOV	3.1	1.75	5.4	5.13	4.8	4.66	6.2	5.44
DEC	1.4	1.92	1.2	1.25	1.1	1.16	1.7	1.27
(APR-OCT)	23.09	12.11	23.09	12.10	23.10	12.12	23.13	12.13

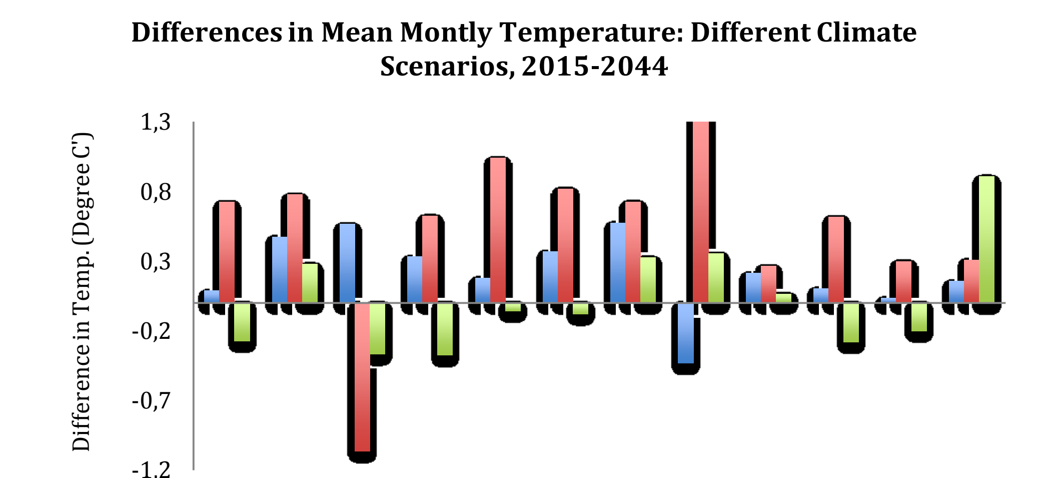
Source: generated by author - data from Bogazici University Climate Change Group.

The average percentage change does not reflect the fluctuations that affect management decisions and adaptation strategies in future periods. The Monthly mean temperature and precipitation ratio changes as shown in Figure 16-17. With the Warm/Dry scenario winter months will have larger changes in temperature, while the summer months have larger changes with the Median and Cold/Humid scenarios. The Warm/Dry scenario has the largest change in temperature except for December. The Warm/Dry climate model with the A2 scenario has the highest value of average maximum and minimum temperature for the whole period (2015-2044) at 15^0C and 12.3^0C respectively, and the Cold/Humid climate model with the A1B scenario has the lowest ones with 13^0C and 13.2^0C respectively. In the case of precipitation for the A1B scenario, the Cold/Humid climate model has the largest change in a positive way, and the Median climate model has the lowest and mostly negative change except for the month of January. Precipitation changes were higher during the harvest season; i.e. September and October for the Cold/Humid climate model as compared to the other climate models.

The effect of elevated CO_2 was selected according to the IPCC climate scenarios in the CropSyst model. The atmospheric CO_2 concentrations were taken as the estimates used in the climate modeling experiments, which on average were 333 ppm for the 1971–2000 baseline, and 718 ppm and 566 ppm for 2015–2100 for the A2 and A1B scenarios respectively. CO_2 and non-

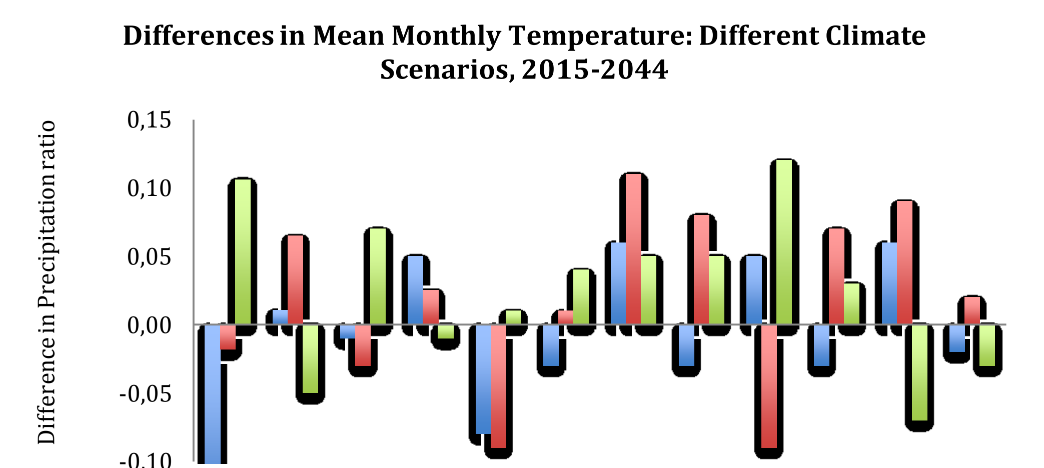
CO_2 enhancement conditions were generated for each climate model and scenario.

Figure 16 – Differences in Mean Monthly Temperature for Selected Climate Models, 2015-2044



	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Median	0,09	0,47	0,57	0,33	0,18	0,37	0,57	-0,43	0,21	0,10	0,04	0,16
Warm/Dry	0,72	0,78	-1,07	0,62	1,04	0,82	0,73	1,46	0,26	0,62	0,30	0,31
Cold/Humid	-0,28	0,28	-0,37	-0,38	-0,06	-0,08	0,33	0,36	0,06	-0,28	-0,20	0,91

Figure 17: Differences in Mean Monthly Precipitation for Selected Climate Models, 2015-2044



	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Median	-0,15	0,01	-0,01	0,05	-0,08	-0,03	0,06	-0,03	0,05	-0,03	0,06	-0,02
Warm/Dry	-0,02	0,06	-0,03	0,03	-0,09	0,01	0,11	0,08	-0,09	0,07	0,09	0,02
Cold/Humid	0,11	-0,05	0,07	-0,01	0,01	0,04	0,05	0,05	0,12	0,03	-0,07	-0,03

Source: based on by the climate scenarios result from Bogazici University, Climate Change Department

4.3.2.3. Soil Characteristic

Another important input in the Cropsyst model is the specification of soil conditions. The soil type was assumed to be the same for the representative vineyard in the Niagara Peninsula, and all varieties were calibrated to this soil and weather in the Cropsyst model. Table 6 shows the soil profile and initial soil conditions. The soil texture characterization varies depending on the depth, but on average contains 47% clay, 23% silt, and 30% sand. CropSyst assesses the hydraulic properties of the soil according to its texture. Soil properties are assumed to be homogeneous over the entire simulated crop area.

Table 6: Soil Profile and Initial Soil Conditions at Niagara Peninsula

Depth	0-0.18m	0.18-0.44m	0.44-0.61m	0.61-1.0m
Sand (%)	29	30	28	33
Clay (%)	50	42	47	50
Silt (%)	21	28	25	17
Organic Matter (%)	0.93	0.87	0.87	0.84
NO3 (kgN/ha)	12	10	4	10
NH4 (kgN(ha)	10	9	5	20
Permanent Wilting Point (m3 /m3)	0.281	0.219	0.24	0.243
Field Capacity	0.409	0.346	0.361	0.348
pH	7	7	7.3	7.9

Source:Canadian Soil Information Systems, Soils of the Regional Municipality of Niagara – representative farm in Niagara on the Lake

4.3.2.3. Phenological Data

Plant phenology development is driven by temperature and photoperiod. The CropSyst model takes into account the effect of light, water, nitrogen, and CO_2 on crop growth. Winegrape yield is calculated from total biomass accumulation during the crop season using the harvest index approach that is responsive to water stress. CropSyst does not simulate the effect of weeds, diseases or pests. Crop response to elevated CO_2 in CropSyst is considered a linear positive effect (Tubiello et al., 2000; Donatelli et al., 2002). For this study current cultivars and cultural practices were used as CropSyst crop parameters. Parameters for the simulation of winegrape varieties for the region were taken from the Brock University Cool Climate Oenology and Viticulture Institute and were further refined using available information about crop phenology and morphological, physiological, and biophysical characteristics.

In-season grapevine development is strongly influenced by air temperature. This average heat accumulation is often referred to as Growing Degree Days (GDD) and can be used to calculate important stages in vine development (bloom, veraison, and maturity). During the specific development stages, when the required daily accumulation of average air temperature above a base temperature and below a cutoff temperature is reached (Finger and Schmid, 2007). 10°C is generally considered as the thermal baseline for grapevine development. Cumulative GDD is a running total of GDD during the vine growing season from April 1 through October 15 (Winkler et al., 1974). GDD are calculated by subtracting 10 from the average daily temperature (°C). If the resulting value is less than 0, then it is set to 0. Thus, daily GDD units are always positive. This is the GDD equation that is used to calculate daily GDD units:

$$GDD = \left(\frac{T_{max} + T_{min}}{2}\right) - 10$$

The GDDs, number of frost days and $T_{max} > 30^{o}C$ were calculated for the 3 climate scenarios (Table 7). Each grape variety would be harvested in early September with the Warm/Dry scenario (GDD: 1557-1966), while they would be harvested in late September for Median scenario (GDD: 1414-1772) and in early October with the Cold/Humid scenario (GDD: 1282-1602). The number of frost days during the growing season was 2 for the Warm/Dry scenario, 6 days in the Median scenario, and 11 days in the Cold/Humid scenario. The Warm/Dry scenario had the largest number of days with temperatures greater than 30°C followed by the median scenario and the Cold/Humid scenario.

Table 7: Agro-climatic indicators

	Median	Warm/Dry	Cold/Humid
	Harvest Date (1st Sep – 15th Oct)		
Average Annual GDD	1414 – 1772	1557 – 1966	1282 – 1602
Growing Season (1st April to 15th October)			
Frost Days	6	2	4
$T_{max} > 30^{0}C$ Days	26	69	9

Source: Generated by author with data from Bosphorus University Climate Change Working Group

The number of GDD for various stages of growth varies by variety (Table 8). White varieties i.e. Chardonnay and Riesling, mature earlier than red varieties. Chardonnay, Riesling, and Pinot Noir's GDD are 1267, 1380, and

1251 respectively. Cabernet Sauvignon has the greatest number of GDD, i.e. 1520. Merlot and Cabernet Franc also have higher GDD than white varieties, i.e. 1474 and 1267 respectively. The number of GDD for Bud-break, Flowering and Fruit Growth stages' varies depends upon the variety.

Table 8: Phenology Milestones on a Per Varietal Basis for Varieties Grown on the Niagara Peninsula

GDDs Necessary to Reach Phenology Milestones				
Thermal Time	Bud Break	Florasion	Verasion	Maturity/Harvest (GDD)
Chardonnay	45-55	350	1068	1267
Riesling	50-60	349	1173	1380
Cab. Sauvignon	80-90	385	1181	1520
Cab. Franc	40-50	350	1068	1367
Merlot	55-65	383	1128	1474
Pinot Noir	55-65	334	1014	1251

Source: These values are a permutation of values from Van Leeuwen et al., 2008, 1974 Winkler Heat summation

Bud break and harvest date were determined after discussion with Ontario Grape Growers and evaluating Ontario Marketing Board Annual reports. The information was used with the CropSyst Model's phonological data. It was assumed that all varieties have the same bud break date i.e. the 5th of April. The harvest date was determined based on the number of GDD's required for maturity. Early ripening varieties such as Chardonnay, Riesling and Pinot Noir had harvest dates of 12th September, 13th September and 26th September respectively. Late ripening varieties, e.g. Cabernet Franc, Cabernet Sauvignon and Merlot had harvest date of the 15th of October, 28th of October and the 14th of October respectively. More phenological parameters are needed to calibrate the CropSyst model (Table 9). Most of these parameters are the same for all varieties in a given region. The only exception is the base temperature for development. This value is zero for the Niagara Peninsula. Simulated crops were assumed to receive adequate water and nutrient supply.

Table 9: Calibrated Parameters for the Cropping Systems Dynamic model in CropSyst for a Reference Cultivar of Winegrape on the Niagara Peninsula

Crop Name	Wine Grape
Harvested part	**Fruit**
Photosynthetic pathway	**C3**
Life cycle	**Perennial**
Stem type	**Herbaceous**
Growth Parameters	
Radiation-Use Efficiency at high VPD (g/MJ PAR)	2.8
Water-use efficiency at 1 kPa (g/kg)	4.8
Slope of water-use efficiency function of VPD	0.6
Leaf water potential that begins reducing canopy expansion (J/kg)	-1000
Leaf Water potential that stops canopy expansion (J/kg)	-1300
Optimum daily mean temperature for growth	8
Canopy cover parameters	
Inıtial canopy ground cover (0-1, unitless)	0.050000001
Max. Canopy cover (0-1, unitless)	0.8
Green canopy cover at maturity	0.3
Total canopy cover at maturity (green and senesced)	0.7
Max. Canopy height (m)	1
Root Parameters	
Maximum root depth (m)	1.5
Root sensitivity to stress	0.20000003
Root lenght at emergence (cm)	12
Phenology parameters	
Base temperature for development	0
max. Temperature for development	25
Transpiration Parameters	
ET coefficient at complete canopy ground cover	1.1
Max. Water uptake (mm/day)	12
Leaf water potential at the onset of stomatal closure (J/kg)	-1300
Wilting leaf water potential (J/kg)	-2000
Dormancy Parameters	
Day of year to start searching for beginning of dormancy	330
Minimum number of days in dormancy	90
Dormancy theshold temperature	5
Fruit tree chill requirement (number of hours below 10 C)	100

Source: CropSyst working paper

4.3.2.4. CropSyst Model Calibration

Statistical Analysis

The model's performance was determined using several indexes based on the calculation of correlation and differences between estimated and measured dormancy, flowering and harvest values. Results obtained from data were analyzed calculating the correlation coefficient (r), the coefficient of determination (R2), the root mean squared error (RMSE), general standard deviation (GSD), modeling efficiency index (EF), coefficient of residual mass (CRM), mean bias error (MBE), mean absolute error (MAE), and the index of agreement (d-Index) for the predicted and observed values. The Pearson correlation coefficient (r) is the correlation coefficient between measured and calculated values defined as:

$$r = \frac{\sum_{i=1}^{n}(E_i - \bar{E}).(M_i - \bar{M})}{\sqrt{\sum_{i=1}^{n}(E_i - \bar{E})^2.\sum_{i=1}^{n}(M_i - \bar{M})^2}}$$

The RMSE was used to test the accuracy of the model, and is defined as the variation, expressed in the same unit as the data, between simulated and measured values (Loague and Green, 1991):

$$\mathrm{RMSE} = \sqrt{\frac{\sum_{i=1}^{n}(E_i - M_i)^2}{n}}$$

where Ei and Mi indicate the simulated and measured annual values of the year i and n the number of annual values. RMSE represents the typical size of model error, with values equaling or near zero indicating perfect or near perfect estimates. The RMSE was also expressed as a coefficient of variation

(GSD) by dividing it by the mean of the measured yield or an thesis values (Mbar):

$$\mathrm{GDS} = \sqrt{\frac{\sum_{i=1}^{n}(E_i - M_i)^2}{n}}\,\frac{100}{\overline{M}} = \mathrm{RMSE}\,\frac{100}{\overline{M}}$$

The accuracy of the model was also evaluated using an index based on the squared of the differences, the modelling efficiency index (EF):

$$\mathrm{EF} = 1 - \frac{\sum_{i=1}^{n}(E_i - M_i)^2}{\sum_{i=1}^{n}(M_i - \overline{M})^2}$$

EF values greater than 0 indicate that the model estimates are better predictors than the average measured value, with negative values indicating the opposite. A EF value equal or near 1 means a perfect or near perfect estimate.

To measure the tendency of the model to overestimate or underestimate, three statistics were used: the coefficient of residual mass (CRM), the mean bias error (MBE) and the mean absolute error (MAE):

$$\mathrm{CRM} = 1 - \frac{\sum_{i=1}^{n} E_i}{\sum_{i=1}^{n} M_i}$$

$$\mathrm{MBE} = \sum_{i=1}^{n} \frac{E_i - M_i}{n}$$

$$\mathrm{MAE} = \sum_{i=1}^{n} \frac{|E_i - M_i|}{n}$$

A negative CRM indicates a tendency for the model to overestimate (Xevi et al., 1996). A positive bias error indicates a tendency to over predict a variable while a negative bias error implies a tendency to under predict a variable.

MAE values near or equal to zero indicate a better match along the 1:1 line comparison of estimated and observed values (Rasse et al., 2000).

Willmott (1981) proposed an Index of agreement (d) defined as:

$$d = 1 - \frac{\sum_{i=1}^{n}(E_i - M_i)^2}{\sum_{i=1}^{n}(|E_i - \overline{M}| + |M_i - \overline{M}|)^2}$$

If the model is perfect, then observed values are equal to simulated values and d=1. If the model predictions are identical in all cases and equal to the average of the observed values, d=0. These limiting values are the same as for EF, but for other cases, the two criteria will have different values.

Calibration and Validation Results

Time-series yield data for Chardonnay, Riesling, Cabarnet Franc, Cabarnet Sauvignon, Merlot, and Pinot Noir were obtained from the Cave Spring farm in the Niagara Peninsula. CropSyst was used to predict the historical yield. This was validated and calibrated with Cave Spring Vineyard data from 2004-2007. Then, the model used to simulate future yields for the 30 years period from 2015-2044.

Calibration for Riesling Variety

The model calibration for the Riesling variety was undertaken using yield data from Cave Spring's experimental site for the period 2004-2007. The results of the yield calibration show perfect correspondence between mean values of observed and simulates. The Pearson's r value ($r = 0.96$) is significant at the $p < 0.05$. The coefficient of determination R indicates that 92% of the total variation is explained by the model.

Validation of Riesling Variety

Model validation compared the simulated and observed values. In addition, there are several other statistical measures available to evaluate the association between predicted and observed values. The results of Riesling evaluation shows a good correspondence between mean values of observed and simulated data, with slightly lower standard deviations for simulated values. The RMSE index value is fairly low (0.36) and it indicates near perfect estimates. Moreover, the percentage of GSD (12%) indicates how the model works well in simulating yield data. However, EF (0.28) is greater than 0 and it indicates that the model estimates are better predictors than the measured value. The CRM index value (0.04) and MBE index values (-0.13) (a negative bias error implies a tendency to under-predict a variable) confirm the goodness of this estimate and a slight tendency to underestimate the value. MAE (0.33) is close to zero and indicates a better match along the 1:1 line comparison of estimated and observed values. D-index value (0.99) is very close to 1, which suggests that the observed values are very similar to simulated values (Table 10).

Table 10: Calibration and Validation Results for the Riesling Variety

Riesling			Estimated	Measured
			Yield	
Maximum	3.5	Mean	2.93	3.07
Minimum	2.5	St. Deviation	0.12	0.51
Number of samples (n)	3	Minimum	2.8	2.5
Pearson Coefficient (r)	0.96	Maximum	3.0	3.5
Coefficient of Determination (R2)	0.92			
Root Mean Square Error (RMSE)	0.36			
General Standard Deviation (GSD)	12			
Modelling Efficiency Index (EF)	0.28			
Coefficient of Residual Mass (CRM)	0.04			
Mean Bias Error (MBE)	-0.13			
Mean Absolute Error (MAE)	0.33			
Index of agreement (d-index)	0.99			

Calibration for Cabernet Franc Variety

The Pearson's r value (-0.54) is negative and significant at the $p< 0.05$ level. The coefficient of determination R indicates that 29% of the total variation is explained by the model.

Validation of Cabernet Franc Variety

The results for Cabernet Franc evaluation show a good correspondence between mean values of observed and simulated data, with a little bit higher standard deviations for simulated values. The RMSE index value is fairly low (0.85) which also indicates that near perfect estimates. How the model works well in simulating the yield data is shown by the percentage of GSD (24%). EF (-5.70) points out that the measured values are better predictors than the model estimates. The CRM index value (0.03) and MBE index values (-0.10) confirm the goodness of this estimate and it has a slightest tendency to underestimate. MAE (0.83), whose value is near to zero, indicates a better match along the 1:1 line comparison of estimated and observed values. The d-index value (0.96) is very close to 1, which indicates that the observed values are very similar to simulated values.

Table 11: Calibration and Validation Results of Cabernet Franc Variety

Cabernet Franc			Estimated	Measured
			Yield	
Maximum	4.3	Mean	3.47	3.57
Minimum	2.8	St. Deviation	0.76	0.40
Number of samples (n)	3	Minimum	2.8	3.2
Pearson Coefficient (r)	-0.54	Maximum	4.3	4.0
Coefficient of Determination (R2)	0.29			
Root Mean Square Error (RMSE)	0.85			
General Standard Deviation (GSD)	24			
Modelling Efficiency Index (EF)	-5.70			
Coefficient of Residual Mass (CRM)	0.03			
Mean Bias Error (MBE)	-0.10			
Mean Absolute Error (MAE)	0.83			
Index of agreement (d-index)	0.96			

Both the Calibration and Validation tests are significantly related for Riesling. However, the Validation tests have more consistent results than the Calibration test for Cabernet Franc. These statistics show that Validation tests give better results for consistency between actual and measured Riesling and Cabernet Franc yield values. Although calibration and validation were applied to other varieties, for the purpose of being precise only one red (Cabernet Franc) and one white (Riesling) variety is demonstrated here.

4.3.3. Net Present Value (NPV)

The NPV is defined as the present value of future cash flows minus the costs of investment (Ross et al., 2003). Present values are calculated by discounting future cash flows using the opportunity cost of capital or discount rate. This method takes into account the time value of money[7] when evaluating an investment. Projects with positive NPV are deemed to be "acceptable" in that they will result in increased wealth. If two mutually exclusive investments are being compared, the one with the greatest NPV will result in the greatest increase in wealth. NPV is calculated using the following equation (Copeland and Weston, 1988):

$$NPV = \sum_{t=0}^{N} \frac{CF_t}{(1+r)^t} - I_0$$

In the above equation Copeland and Weston (1988) define as the net cash flow in a time period, as the initial cash expenditure, is the discount rate, and as the number of years considered for the investment. The producer's net present value of farm income for the vineyard is represented by Z. This can be expressed as:

$$Z = \frac{[\sum_t^T \sum_i^I \sum_k^K y_i(k)[x_{ti}(p_{ti} - c_{ti})] - FC_t]}{(r+\propto)^t}$$

Where:

[7] The time value of money refers to an assumption regarding investor preferences; that is, all other things being equal, an investor prefers to receive returns (i.e. positive cash flows) earlier rather than later. The discounting done in a NPV calculation puts all cash flows associated with an investment on an equivalent time bases.

Z: expected net present value of farm income resulting from the planting decision with respect to climate scenarios.

x(it): area planted to each variety $i \in I$ at the beginning of period t

y(ti): denotes the yield of variety i to be planted in period t while (i = 1,…, 6) and (t = 1,…, T)

y(i)(k)[p(ti)-c(ti)]: Gross margin per acre for variety i under k different climate scenarios in year t

FC(t): Fixed cost in year t

$\propto$: Discounted rate.

The primary objective of this study is to calculate the net present value of a land allocation to different winegrape varieties in a vineyard over three climate scenarios. Simulated yields and future costs and revenues were integrated into an economic model in order to calculate the Net Present Value varying selected discount rates. The model used in this analysis can be used to compare the net present value of the variety land allocation across the three climate scenarios to investigate the impact of alternative climate change scenarios in producer returns.

4.3.3.1. Discount Rate

The discount rate should reflect the opportunity cost of capital in order to be consistent with wealth maximization (Copeland and Weston, 1988; McCarl and Spreen, 1997). The larger the discount rate, the smaller will be the present value of benefit that occurs in future periods, hence the less likely that the flow of benefit from that investments will provide the greater present value. Discount rates reflect the relative riskiness of an operation. Adoption as an investment decision may be risky for producers, and thus it will only occur if the expected return from adoption is sufficiently high to compensate for the risk (Ross et al., 2003).

The discount rate has an important effect on investment decisions. In general the rate of return on investments reflects the degree of risk involved. For example; if producers of orchards, which is another perennial crop, doing NPV analysis, have to choose a discount rate, which equals the rate of return of investments with regards to risk (Goedegebure, 1986). Therefore, the discount rate can vary, depending on the kind of fruit, variety, planting systems etc. A typical project involves upfront costs, with the flow of benefits occurring over later periods. If so, the lower the discount rate, the more attractive is the project; i.e. the higher its net present value. If the discount rate is set too high, desirable projects may be rejected. If it is set too low, undesirable projects may be approved. Lower discount rates encourage investors to adopt projects that offer returns in future time periods (Harrison, 2010).

An investment essentially trades off initial costs against delayed benefits. This is conventionally achieved by calculating the NPV of the investment via a discount rate which is influenced by positive time preference. In its a simplest form, if considering the opportunity cost of capital, risk-averse people might choose a relatively low social discount rate dictated by the rate of return on riskless investments; i.e. government bonds, etc. This is because society can spread the risk across all members of society causing the risk component of the discount rate to approach zero or the emphasis social places on long time horizon for the society (Sassone and Schaffer, 1978). For the private individual the opportunity cost of capital should be relatively high; therefore, agricultural discount rates, as a private investment might be higher than the social discount rates (Bateman et al., 2002).

In the literature, the discount rate for a perennial enterprise budget ranges from 4% to 10% (Khanna et al., 2008; Styles et al., 2008, Huisman et al., 1997; Nalley et al., 2012). Usually the discount rate for an enterprise is determined by its level of riskiness, where the riskier the enterprise, the higher the discount rate. Khanna et al., 2008 used a discount rate of 4%, Styles et al. (2008) used a discount rate of 5% to calculate their NPV.

Over the last three years the prime rate in Canada has been 3% so as a minimum for a producer starting out the rate should be prime plus some risk component. Furthermore, this rate can increase substantially if the producer's planned investment is for more than 40 years. Therefore, in this analysis, the discount rate selected was 4% and it is used in the calculation of the NPV over the 30-year planning horizon. In addition, a sensitivity analysis was undertaken with 5% and 6% discount rates.

4.3.3.2. Monte Carlo Simulation

Simulation models are useful for representing agricultural systems as they can be used to test hypotheses and explore alternative management scenarios. Simulation models can be used to investigate innovative practices and policy (Bechini and Stöckle, 2007). Simulation models may be static or dynamic over time and may contain deterministic or stochastic variables (Carson, 2003). A static model considers only one period in time while dynamic model include several time periods. Deterministic models do not contain random variables, while stochastic models allow for one or more parameters to be random (April et al., 2003). Many simulation techniques exist and Monte Carlo (MC) is one of the most widely used. The MC method of simulation relies on choosing values for variables which are based on the expected probabilities, producing hundreds or thousands of simulated outcomes. This method may then be subject to further statistical analysis (Kwak and Ingall, 2007).

4.3.3.2.1. Prices

The MC simulation was undertaken using Microsoft Excel. The model makes the traditional assumption that grape prices follow a geometric Brownian motion process (Cyr and Hanagriff, 2010), generating a lognormal price distribution specified as

$$dP = \mu P dt + \sigma P dz$$

where dz follows a Wiener process ($dz = \varepsilon\sqrt{dt}$) with ε representing a random draw from a standardized normal distribution.

The primary assumption underlying the model is that grape prices are lognormally distributed. "The lognormal distribution is often a more reasonable distribution of many asset prices (which cannot become negative) than the normal distribution" (Benninga, 2008, p502). In this study, $X = \exp(\sigma Z + \mu)$ is random variable, where $Z \sim N(0, 1)$, and lognormally distributed (μ,σ^2) where parameters μ and σ are the mean and standard deviation respectively of the log X. The definition was determined by $\sigma Z + \mu \sim N(\mu, \sigma^2)$ (Benninga, 2008).

Let S^0 denote the price of some variety at time t = 0. Then follow the commodity price at regular time intervals t = 1, t = 2, . . . , t = n. Let S_t denote the commodity price at time t. The model was used for the (random) evolution of the price process $S_0, S_1, . . . , S_n$ for $1 \le k \le n$, and $S_k = S_{k-1}V_k$, where the

V_k are strictly positive and IID—i.e., independent, identically distributed[8]. In this context V_k is the volatility of prices between the specified periods. Consequently, taking logarithms:

$$\log(V_1) = \log\left(\frac{S_1}{S_0}\right) = \sum_{t=1}^{k} \log\left(\frac{S_1}{S_0}\right)$$

In view of the Central Limit Theorem[9], for example, if log X_1 has finite variance, then log X_1 must have a normal distribution. Therefore, it is reasonable to hypothesize that X_k is lognormal, and that X_k can be written as we may write $X_k = \exp(\sigma Z_k + \mu)$, where the Z_k are IID standard normal (Sharpe, n.d.).

The parameters and are estimated from the historical price data. If you have a sample of n IID normal varieties with unknown mean and standard deviation , then the sample mean;

$$\bar{Y} = \frac{Y_1 + \cdots + Y_n}{n}$$

n is an unbiased estimator of and $\frac{\sum(Y_k - \bar{Y})^2}{n-1}$ is an unbiased estimator of (Sharpe, n.d.).

The historical volatility was calculated over an 8 years period. The historical volatility estimator assumes that volatility is constant over the estimation

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8 IID—i.e., independent, identically distributed: Two random variables X and Y (S and V in this case) are independently distributed or independent, if knowing the value of one of the variables (S) provides no information about the other (V) (Stock and Watson, 2007)

9 Central Limit Theorem (CLT): under general conditions, the distribution of is approximated by a normal distribution when n is large. According to the CLT, when n is large the distribution of is approximately

period and the forecast period (Sharma, 1998). Grape prices for one variety are S_0 through S_n, which were computed the n years. $X_1 = \frac{S_1}{S_0}$ through $X_n = \frac{S_n}{S_{n-1}}$ and then set $Y_k = log X_k$.

In the financial literature,

$$R_k = \frac{S_k - S_{k-1}}{S_{k-1}} = X_k - 1$$

is called the return for the k^{th} day. In this analysis, logarithmic return was calculated on a yearly basis to calculate volatility.

In order to estimate the input parameters of μ and σ the variable of Return $R_i = \ln(\frac{S_t}{S_{t-1}})$ was calculated based on annual average grape prices. R_i is the log return while S_t is the price at time t. Unfortunately, a long time series of Ontario wine grape prices is relatively difficult to obtain. Input parameters (μ, σ, and log-return) and historical grape prices data are graphically summarized in Tables 12 through 14 for a seven year period from 2005 through 2012 for each grape variety. Based on the available data, volatilities[10] of each variety were calculated using the following equation (Gujarati, 2003):

$$V = \sqrt[2]{\frac{1}{(n-1)} \sum_{i=1}^{n} (x_i - \bar{x})^2}$$

[10] As noted in the introduction to this chapter; financial time series, such as stock prices, echange rates, inflation rates, etc. often exhibit the phenomenon of **volatility clustering** , that is, periods in which their prices show wide swings for an extended time period followed by periods in which there is relative calm. Knowledge of volatility is of crucial importance in many ares. For example, considerable macroeconometric work has been done in studying the variablity of inflation over time (Gujarati, 2003).

Table 12: Wine Grape Prices Over The Period 2006-2012

	2006	2007	2008	2009	2010	2011	2012
Chardonnay	$1,494	$1,524	$1,509	$1,396	$1,410	$1,424	$1,445
Riesling	$1,442	$1,471	$1,471	$1,468	$1,382	$1,396	$1,417
Cab. Sauvignon	$2,039	$2,080	$2,038	$1,875	$1,875	$1,875	$1,875
Cab. Franc	$1,751	$1,786	$1,822	$1,676	$1,676	$1,676	$1,676
Merlot	$2,060	$2,101	$2,059	$1,894	$1,894	$1,894	$1,894
Pinot Noir	$2,060	$2,101	$2,101	$1,933	$1,933	$1,933	$1,933

Source: Grape Growers Ontario Marketing Board

Table 13: Log-Return of the Historical Prices

LOG-Return	2006	2007	2008	2009	2010	2011	2012
Chardonnay	-1.99%	0.99%	7.78%	-1.00%	-0.99%	-1.46%	-0.96%
Riesling	-1.99%	0.00%	0.20%	6.04%	-1.01%	-1.49%	-0.98%
Cab. Sauvignon	-1.98%	-2.00%	8.35%	0.00%	0.00%	0.00%	0.00%
Cab. Franc	-1.99%	2.04%	8.34%	0.00%	0.00%	0.00%	0.00%
Merlot	-1.97%	2.02%	8.35%	0.00%	0.00%	0.00%	0.00%
Pinot Noir	-1.97%	0.00%	8.33%	0.00%	0.00%	0.00%	0.00%

Table 14: Characteristics of Grape Prices

Log	Mean	St. Deviation	Volatility
Chardonnay	7.280	0.065	3.72%
Riesling	7.267	0.009	2.47%
Cab. Franc	7.452	0.012	3.14%
Cab. Sauvignon	7.578	0.016	3.08%
Merlot	7.583	0.016	3.22%
Pinot Noir	7.601	0.014	3.03%

It is possible to run Monte Carlo simulations in a Microsoft Excel spreadsheet. Using the Data Table function to address simple what if questions, sensitivity analysis, variance analysis and even Monte Carlo (Stochastic) analysis. Excel can estimate 1000 random iterations to generate future prices. “1000 iterations provide a statistical chance of getting sufficient extreme values to make the variance analysis meaningful. This is important because as the number of iterations increase the variance of the average output decreases”

(Verschuuren, 2013, p.167). Excel can produce random numbers; using RAND( ) and RANDBETWEEN( ), that have Uniform Distribution (all values have an even chance of selection), where the values are between the minimum and maximum values and have the same probability of being chosen. NORMSDIST(z) returns the cumulative distribution function for the standard normal distribution. NORMSINV(probability) returns values of z for specified probabilities (Jackson and Staunton, 2001). NORMSINV function is used in this Monte Carlo analysis that;

$$= NORMINV(RAND(\,), MEAN, STANDARD_{DEV})$$

This formula generates random prices by using the previous year price and the volatility. Annual volatility was assumed to be constant for each year. Grape prices for each variety for each year of the planning period (2015-2044) was calculated using the following command;

$$= PRICE_{PREV.YEARS} * (1 + NORMINV(RAND(\,), 0, VOLATILITY))$$

It was assumed that there would not be any major exogenous shocks affecting prices. Monte Carlo (MC) simulations procedures were used for the price projections between 2015-2044.

4.3.3.3. Variable and Fixed Costs

Costs of production for each grape variety i.e. red and white were projected using data from the 2009 Grape Growers Ontario’s report (Slingerland, 2009) (Table 15 and 16). Cost of production for white varieties was used for

Chardonnay, Riesling, and Pinot Noir while red variety cost data were used for Cabernet Franc, Cabernet Sauvignon, and Merlot. The per acre costs for each of the six crops included fixed costs, depreciation, and variable costs excluding crop insurance. Insurance costs were excluded from the projections since they were treated separately in the agro- economic models. It was assumed that producers own their machinery and that it did not need to be replaced during the planning horizon. In addition, the producers were assumed to own their land and buildings. Machine and building maintenance and repair costs were included in the projections. The cost of harvesting was estimated to be $182 per acre. A 100-acre vineyard is planted with vines spaced 4 feet apart and 9 feet between rows. The standard 4' x 9' planting contains 1,210 vines per acre on average. One acre has 9 rows with approximately 134 vines per row. Vine cost was estimated to be $2.70 per plant for all varieties, including the cost of shipping, and 2% replanting each year.

The cost of production available for the year 2009 was projected into the future. 3% interest rate was applied on cost of 2009 for planning horizon. Salaries for hired labor were excluded from the cost projections. Labor cost for the hired labor was introduced separately in the models. Labor cost was assumed to increase at a rate of 2% per year starting at $17 per hour and $12 per hour for skilled and unskilled labor. It was also assumed was that there would not be any major change in technological, infrastructure adjustments or any other shocks that would affect the overall production environment.

Table 15: Establishment and Production Costs of Red Grape Varieties in Ontario, 2009

Year		Preplant	1st	2nd	3rd	4th	Mature Vineyard 5-25th
Variable Costs							
Operation Costs							
	Hours	*4.2*	*28.0*	*22.6*	*44.1*	*44.0*	*71.5*
Labor Cost (Hand)	$	72	347	280	547	546	887
	Hours		*19.8*	*28.4*	*30.7*	*26.5*	*31.7*
Labor Cost (Machine)	$		341	488	528	456	545
Machine Cost*[11]		69	246	356	389	353	445
Fertilizer			14	17	53	73	83
Insecticides				43	86	130	130
Fungicides			63	178	357	541	541
Herbicidies				19	36	45	56
Grape vines, ($2.70/vine)			3267				
Custom Trellis: materials, labor			5306				
Training:stakes, material			1162				
Custom Planting			724				
Custom Plowing		23					
Cover Crop		46	46	23	23	23	23
Consulting fees		32	32	32	32	32	32
Irrigation			171	171	171	171	171
Bird Control					124	124	124
Custom Harvest/delivery						182	81
Marketing board fees					29	59	25
Interest on operating capital		65	513	602	726	811	38
Land rental							
Land preparation		850					
Tile Drainage		2948					
Total Variable Costs[12]**		**4105**	**12218**	**2209**	**3101**	**3546**	**3181**
Fixed Cost							
Machine costs: depreciation		59	144	178	192	192	248
Interest on investment		13	31	39	42	42	51
Other overhead		107	214	214	214	214	214
Measurable fixed costs		**178**	**389**	**431**	**448**	**448**	**513**
Total Establishment Cost		**4283**	**12607**	**2640**	**3549**	**3994**	**3694**

[11] includes maintenance, fuel and repair

[12] it does not include crop insurance

Table 16: Establishment and Production Costs of White Grape Varieties in Ontario, 2009

Year		Preplant	1st	2nd	3rd	4th	Mature Vineyard 5-25th
Variable Costs							
Operation Costs							
	Hours	*4.2*	*28.0*	*22.6*	*44.1*	*44.0*	*71.5*
Labor Cost (Hand)	$	72	347	280	547	546	887
	Hours		*19.8*	*28.4*	*30.7*	*26.5*	*31.7*
Labor Cost (Machine)	$		341	488	528	456	545
Machine Cost[13]		69	246	356	389	353	445
Fertilizer			14	17	53	73	83
Insecticides				43	86	130	125
Fungicides			63	178	357	541	541
Herbicidies				19	36	45	56
Grape vines, ($2.70/vine)			3267				
Custom Trellis: materials, labor			5306				
Training:stakes, material			1162				
Custom Planting			724				
Custom Plowing		23					
Cover Crop		46	46	23	23	23	23
Consulting fees		32	32	32	32	32	32
Irrigation			171	171	171	171	171
Bird Control					124	124	124
Custom Harvest/delivery						203	81
Marketing board fees					28	58	23
Interest on operating capital		65	513	602	725	815	34
Land rental							
Land preparation		850					
Tile Drainage		2948					
Total Variable Costs[14]		**4105**	**12232**	**2209**	**3099**	**3570**	**3170**
Fixed Cost							
Machine costs: depreciation		59	144	178	192	192	248
Interest on investment		13	31	39	42	42	51
Other overhead		107	214	214	214	214	214
Measurable fixed costs		**178**	**389**	**431**	**448**	**448**	**513**
Total Establishment Cost		**4283**	**12621**	**2640**	**3547**	**4018**	**3683**

Source: Grape Growers Ontario, Establishment and Production Costs for Grapes in Ontario, 2009 Economic Report

[13] includes maintenance, fuel and repair
[14] it does not include crop insurance

4.3.4. Available and Proposed Income Stabilization Programs

4.3.4.1. The Canadian Agricultural Income Stabilization Program (CAIS)

The Canadian Agricultural Income Stabilization Program (CAIS) provides agricultural producers with a long-term whole farm risk management tool that protects them against declines in farm income. Two types of insurance, with different levels of coverage, are made available to grape producers. These are Individual Production (Crop) Insurance that are available at 85%, 80%, 75% and 70% coverage and the new AgriStability Insurance that replaced CAIS in Growing Forward 2 (2013-2018).

The AgriStability program is based on the principle that government and participants share the costs of stabilizing the annual income of the participant's farm business. It was introduced as a financial risk management tool, but does not cover the first 30% of margin reduction[15]. The participation fee paid by the producer is estimated by multiplying the reference margin by 0.45% and multiplying this by 70% (Agriculture and Agri-food Canada, 2013). An administration fee of $55 is added to the calculation as the premium paid. An AgriStability payment is triggered when the Program Year Margin declines more than 15% below the Program year Reference Margin. Government funds provide coverage for 70% of a producer’s margin decline. The program

[15] Margin reduction is estimated by taking the difference between the reference margin which is the Olympic average margin of the previous five years and the production margin of a given year provided that the reference margin is non-negative.

compares the current year production margin (net income this year) to the reference margin (the Olympic average of the 5 most recent production margins, or the adjusted expenses; which is lower). If the production margin falls below the payment trigger (70 per cent of the reference margin), AgriStability will pay 70 percent of the difference. According to Growing Forward 2 Agristability program, "if you did not farm and did not report farm income (or loss) to Canadian Revenue Agency in each of the previous 5 years, Reference Margin will be based on your previous 3 years average" (Agriculture and Agri-Food Canada, 2013, p:3). As mentioned earlier, this representative vineyard was assumed to newly established. There would be no income (revenue) in the first 2 years (2015-2016) following the establishment of the vineyard. Moreover, 2 of 3 years of production margins must be positive to be eligible for the Agristability program. For all of these reasons, this representative vineyard was eligible for the Agristability program from 2021 to 2044.

The Province of Ontario Individual Crop Insurance Program for grapes had a coverage rate of 85%, 80%, 75% and 70% of production. The expense for individual crop insurance were computed based on the expected crop yield during the simulation period of 30 years multiplied by the respective crop price for each of the 4 different premium rates (Table17).

Table 17: 2014 Grape Insurance Premium Rates

Grape Category	Premium rate by coverage level (% of total liability)			
	70%	75%	80%	85%
Vinifera	4.06%	4.39%	4.72%	5.53%

Source: Agricrop Ontario

The annual production insurance premium[16] was calculated based on a Base premium rate, Guaranteed Value (GV), and Discounts and Surcharges (D/S). The insurance coverage and claims were calculated according to the final average yield (FAY), claim price, coverage level[17], guaranteed production and guaranteed value. Final average yield (FAY) is based on the 6 most recent yields of grapes. Claim prices for each variety were determined by Monte Carlo simulation. The guaranteed production was determined by multiplying FAY by the selected coverage level. This number was used to calculate the guaranteed value[18].

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[16] The premium is calculated using this formula:
AP = base premium rate x Guaranteed Value (GV) x Discount or Surcharges (D/ S)
Base premium rate: The base premium rate is determined at renewal time each year. It was assumed that the base premium rate was the same for the planning horizon.
Guaranteed value: The guaranteed value is determined by multiplying the guaranteed production by selected claim price by variety. Guaranteed value for Brix varieties is the final average Brix at the corresponding claim price x the historical yield. **Discounts and surcharges:** If the producer has been enrolled in a Production Insurance plan for more than one year, the premium rate may be discounted or surcharged.

[17] **Guaranteed Production** is determined by multiplying of Average Farm Yield (AFY) by selected coverage level. If an insured peril causes your actual yield to fall below the guaranteed production, a production claim may be paid on the difference.

[18] **Guaranteed value** converts the guaranteed production into a dollar amount so the premium can be calculated and any production claims can be paid.
(Guaranteed value = Guaranteed production x selected claim price)

4.3.4.2 New Vineyard Support Program (NVSP)

The New Vineyard Support Program (NVSP) is an incentive policy proposal in order to support the newly established vineyards. The goal is to protect the growers against climate change and boost profitability. The assumptions for the NVSP model are as follows:

- The farm size is 100 acres;
- The base yield (BY) is the major constant base component of the program;
- The BY is imported from the CropSyst model and corresponds to a 30 year average of three climate scenarios plus two CO_2 enhancement conditions;
- There are five, five year periods;
- Each five year period variable average yield (AY) is also imported from the CropSyst model and applicable to three scenarios: Warm/Dry; Median; Cold/Humid, and with and without CO_2 enhancement conditions;
- The maximum amount of support is $1000 per difference yield (DY) (ton/acre);
- The DY is the difference between the fixed BY and variable AY for each period, and valid if the AY is smaller than the BY;
- The support multiplier amount starts with $1000 for the first 5 years of full maturity period (6-10 years) and gradually falls as shown in Table 18:

Table 18: New Vineyard Support Program Multipliers Designated to Five Year Periods

Periods	0-5 years	6-10 years	11-15 years	16-20 years	21-25 years	26-30 years
Multiplier over (BY)	n/a	$1000	$800	$600	$400	$200

- The maximum total amount of support fund allocated per farm/grower is $80.000;
- There is no production and payment applicable to the first 5 years (non-productive period);

To be eligible for the NVSP is; The farm should be newly established; The grapes have to reach the full maturity period (6-10 years); The average yield (AY) should be smaller than the base yield (BY); The support payment is due at the end of each five year period.

CHAPTER 5

RESULTS AND DISCUSSIONS

The wine grape varieties used in this study are Chardonnay, Riesling, Cabernet Sauvignon, Cabernet Franc, Merlot, and Pinot Noir. These varieties were selected because they represent the largest acreage of wine grapes grown in the Niagara Peninsula. The above-mentioned varieties are the ones most in demand by the wineries.

5.1. SIMULATED PRICES, COSTS AND YIELDS

The trends in observed, simulated prices and costs for each grape variety in the Niagara Peninsula are given in Annex 6. Simulated prices increased at different rates for each variety. The projected prices were determined by using actual prices from 2006-2012. Grape variety prices varied due to the volatility of the restricted prices. The prices of Chardonnay and Riesling were found to be increasing more than other varieties. The smallest price change was detected for Cabernet Franc during the 30-year planning horizon. The Monte Carlo projection of grape prices is given in Table 19. Starting prices for the simulation were taken from Grape growers Ontario, 2012 annual report. The 95% Confidence Interval (CI) range of mean price was $1,424-1,481 for Chardonnay, $1,429-1,436 for Riesling, $1,676-1,685 for Cabernet Franc, $1,848-1,879 for Cabernet Sauvignon, $1,885-1,916 for Merlot, and $1,919-1,922 for Pinot Noir.

The cost of production was projected based on the 2009 estimates. The fixed cost was the same for each variety while variable costs were different for white and red grape varieties. Variable costs and fixed cost followed a linear upward trend, which was calculated by applying a 3% fixed interest rate for each year. The per acre fixed cost for all varieties will be $528 in 2015 and $1245 in 2044. The per acre costs are very similar to the white and red grape varieties. The difference in variable costs between the white and red varieties is $11; red wine is $3,181 from year 5 to year 25 while white wine is $3,170 from year 5 to year 25. The differences in variable costs between the red and white varieties are shown in Table 20.

Table 19: Statistical results of Monte Carlo Simulation

2015-2044	Chardonnay	Riesling	Cab. Franc	Cab. Sauvignon	Merlot	Pinot Noir
Starting Price	$1,459	$1,431	$1,676	$1,875	$1,894	$1,933
Min Price	$1,142	$1,415	$1,417	$1,175	$1,946	$1,584
Max. Price	$1,771	$1,489	$1,579	$1,527	$2,290	$1,621
Mean Price	$1,454	$1,433	$1,681	$1,864	$1,900	$1,920
Median Price	$1,435	$1,423	$1,667	$1,834	$1,870	$1,908
Standard Deviation	$445	$52	$67	$249	$243	$26
Percentiles						
5%	$1,022	$1,129	$1,222	$1,392	$1,373	$1,438
95%	$1,983	$1,760	$2,202	$2,435	$2,492	$2,500
25%	$1,247	$1,297	$1,468	$1,636	$1,673	$1,675
75%	$1,638	$1,557	$1,865	$2,062	$2,108	$2,129
95% CI for mean price						
Lower	$1,426	$1,429	$1,676	$1,848	$1,885	$1,919
Upper	$1,481	$1,436	$1,685	$1,879	$1,916	$1,922

Table 20: Differences in variable cost between red and white varieties

Variable Costs	Red Varieties	White Varieties
Insecticides	$130	$125
Marketing Board Fees	$25	$23
Interest on operating capital	$38	$34

Summaries of simulated average yields for each grape variety and climate scenarios with and without CO_2 enhancement are presented in the tables 21 and 22. Based on the observation of those tables, it is clear that CO_2 enhancement has a positive impact on average grape yields for each of the climate scenario. Therefore, the immediate observation would be: CO_2 enhancement provides the best climate condition for all types of wine-grape production. The highest yields (with CO_2 enhancement) occurred as follows: Chardonnay in the Cold/Humid scenario; Cabernet Franc and Cabernet Sauvignon in the Warm/Dry scenario; and finally Merlot and Pinot Noir in the Median scenario. Merlot has the highest yield of 4.5 ton/acre under the Median scenario. The lowest yield of 3.3 ton/acre appears under Warm/Dry scenario for Chardonnay. The most favorable aggregate scenario (including with and without CO_2) according to yield results is Warm/Dry followed by Cold/Humid and the least favorable is the Median.

Table 21: Simulated Yields under Different Climate Scenarios without CO_2 Enhancement

Varieties	Years	Climate Models Projections Warm/Dry	Average Yield (ton/acre) Median	Cold/Humid
Chardonnay	2015-2024	4.2	4.2	3.8
	2025-2034	3.2	3.1	3.4
	2035-2044	2.6	2.5	3.2
	2015-2044	**3.3**	**3.3**	**3.5**
Riesling	2015-2024	3.8	4.1	4.4
	2025-2034	3.7	4.0	3.9
	2035-2044	3.1	3.1	3.2
	2015-2044	**3.5**	**3.7**	**3.8**
Cabernet Franc	2015-2024	4.6	5.1	4.8
	2025-2034	3.6	4.0	3.9
	2035-2044	3.1	3.2	3.3
	2015-2044	**3.8**	**4.1**	**4.0**
Cabernet Sauvignon	2015-2024	4.6	4.2	4.0
	2025-2034	4.4	4.0	3.8
	2035-2044	3.9	3.8	3.6
	2015-2044	**4.3**	**4.0**	**3.8**
Merlot	2015-2024	4.3	4.2	3.9
	2025-2034	4.2	4.1	4.1
	2035-2044	3.6	3.5	3.6
	2015-2044	**4.0**	**3.9**	**3.8**
Pinot Noir	2015-2024	4.2	4.0	3.5
	2025-2034	3.5	3.2	3.0
	2035-2044	2.9	2.8	2.7
	2015-2044	**3.5**	**3.3**	**3.0**

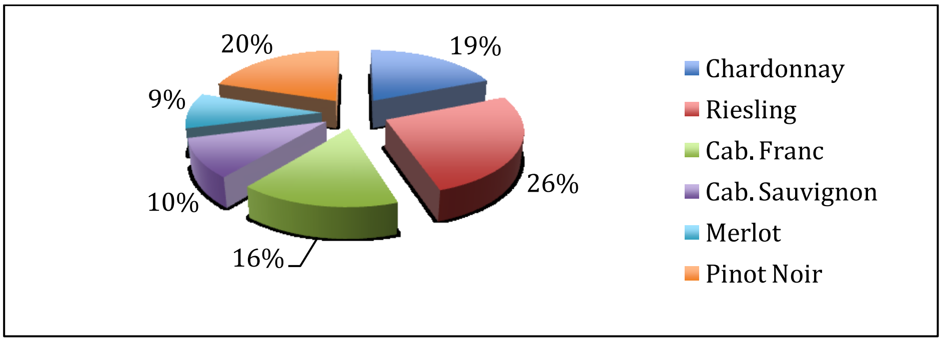
Table 22: Simulated Yields under Different Climate Scenarios with CO_2 Enhancement

Varieties	Years	Climate Model Projections Warm/Dry	Average Yield (ton/acre) Median	Cold/Humid
Chardonnay	2015-2024	4.0	4.4	4.3
	2025-2034	3.2	3.4	3.5
	2035-2044	2.8	2.9	3.1
	2015-2044	**3.3**	**3.5**	**3.6**
Riesling	2015-2024	4.1	4.5	4.7
	2025-2034	4.0	4.3	4.2
	2035-2044	3.2	3.4	3.4
	2015-2044	**3.8**	**4.0**	**4.1**
Cabernet Franc	2015-2024	4.8	4.4	4.0
	2025-2034	4.3	4.1	3.9
	2035-2044	3.6	3.5	3.3
	2015-2044	**4.2**	**4.0**	**3.7**
Cabernet Sauvignon	2015-2024	4.6	4.4	4.1
	2025-2034	4.5	4.3	3.9
	2035-2044	4.2	3.4	3.5
	2015-2044	**4.4**	**4.0**	**3.8**
Merlot	2015-2024	4.5	4.8	4.1
	2025-2034	4.5	4.6	4.2
	2035-2044	3.8	3.9	3.9
	2015-2044	**4.3**	**4.5**	**4.0**
Pinot Noir	2015-2024	3.8	4.7	4.2
	2025-2034	3.5	3.7	3.4
	2035-2044	3.2	3.3	2.9
	2015-2044	**3.5**	**3.9**	**3.4**

5.2. ALLOCATION OF LAND AMONG THE VARIETIES

The representative vineyard in the Niagara Peninsula contained 100 acres. This assumption was determined exogenously from the model. The acreage allocation for each grape variety was determined from existing acreage allocations. Figure 18 provides the allocation of land for each grape variety. Riesling (26%), Pinot Noir (20%), Chardonnay (19%), and Cabernet Franc (16%) have the greatest acre respectively with the highest 26% of the total land area, while Merlot and Cabernet Sauvignon had the least amount of acre with 9% and 10% of the representative 100-acre vineyard respectively.

Figure 18: Allocation of 100-acre vineyard



5.3. FINANCIAL RISK MANAGEMENT TOOLS AND NET PRESENT VALUE OF NET VINEYARD INCOME

5.3.1. Aggregate Farm Income

Numerous studies have shown that the inability to adapt to climate change has negative impacts on agricultural production and communities, and that vulnerability can be reduced and opportunities can be realized with adaptation (Smit and Skinner 2002). One of the means of adapting is through institutions such as financial risk management tools. The results of this study indicate the importance of financial instruments in addressing climate change. This section evaluates the present value of net farm income with and without adaptation under the different climate scenarios and CO_2 enhancement conditions. For all varieties, climate scenarios, and conditions, the present value of net farm income was found to be highest when financial risk management tools were used, i.e. when producers used the Crop insurance program, Agristability program, and New Vineyard Support Program (NVSP).

The results reveal that the largest present value of net farm income occurs when insurance is taken at a maximum 85% coverage level for all climate scenarios, whether CO_2 enhancement occurs or not. The present value of net farm income increases gradually from the Warm/Dry to the Cold/Humid, and then to the Median scenario. The highest present value of net farm income occurs with the Median scenario, with CO_2 enhancement and 85% insurance coverage with a value of $2,021,382. Present values maintain acceptable values with $889,937 under Cold/Humid scenario, $921,698 under Median and $737,548 under Warm/Dry scenario without CO_2 enhancement. Under the condition of without CO_2 enhancement and no insurance payment, present value of net farm income was decreased to $632,967 for the Median scenario, $414,869 for the Cold/Humid scenario, and $213,143 for Warm/Dry scenario. When the crop insurance coverage level has been raised from 70% to 85%, the present value of net farm income has increased for each climate scenario and CO_2 enhancement conditions. For example, the Cold/Humid scenario without CO_2 enhancement increased by $234,734; for the Median scenario without CO_2 enhancement increased by $154,517; and for Warm/Dry scenario without CO_2 enhancement increased by $149,468 (Table 23).

Table 23: The Net Present Value of Net Farm Income with Various Crop Insurance Rates Under Various Climate Scenarios with and without CO_2 Enhancement Conditions

Climate Scenario	Insurance Type	CO_2 Conditions	
		With CO_2	without CO_2
Cold / Humid	No Insurance	$984,511	$414,869
	85%	$1,562,454	$889,937
	80%	$1,406,850	$823,247
	75%	$1,395,632	$693,978
	70%	$1,392,719	$655,203
Median	No Insurance	$1,652,643	$632,967
	85%	$2,021,382	$921,698
	80%	$1,732,890	$838,312
	75%	$1,764,007	$824,667
	70%	$1,682,050	$767,181
Warm / Dry	No Insurance	$753,016	$213,143
	85%	$1,314,684	$737,548
	80%	$1,195,252	$640,328
	75%	$1,183,056	$603,750
	70%	$1,134,351	$588,080

When the proposed New Vineyard Support Program (NVSP) is applied to the representative farm, the Warm/Dry scenario without CO_2 enhancement condition seems to attract the highest amount of support with $78,316 and lowest amount of support is received by the Median scenario with CO_2 enhancement condition with $27,102.

Table 24: New Vineyard Support Program (NVSP) Payment

5 year Periods	With CO_2			Without CO_2		
	Climate Model Projections			Climate Model Projections		
	Warm/Dry	Median	Cold/Humid	Warm/Dry	Median	Cold/Humid
2020-2024	$2,868	$0	$0	$7,808	$102	$1,363
2025-2029	$7,580	$1,248	$5,055	$16,452	$12,841	$11,557
2030-2034	$5,976	$4,929	$7,320	$16,198	$13,433	$12,339
2035-2039	$19,460	$16,666	$16,560	$27,436	$28,793	$24,209
2040-2044	$6,315	$4,258	$5,316	$10,422	$9,958	$8,698
2015-2044	**$42,198**	**$27,102**	**$34,251**	**$78,316**	**$65,126**	**$58,167**

The absence of both Crop Insurance, Agristability and NVSP programs would reduce the present value of total net income for the Cold/Humid scenario with and without CO_2 enhancement by $813,994 and $746,311; for Median scenario with and without CO_2 enhancement by $707,822 and $747,113, for Warm/Dry scenario with and without CO_2 enhancement by $816,300 and $861,030, respectively (Table 24 and Table 25). The largest impact of climate change on the present value of total net income as an aggregate financial management tools was detected in the Warm/Dry scenario without CO_2 enhancement condition.

Table 25: Effects of Financial Risk Management Tools on Present Value of Net Farm Income with various climate scenarios and CO_2 Enhancement Conditions

Climate Scenarios	Financial Management Tools	CO_2 Conditions	
		With CO_2	Without CO_2
Cold/Humid	NO tools	$984,511	$414,869
	%85 Insurance	$1,562,454	$889,937
	%85 Ins. + Agristability	$1,764,254	$1,103,013
	%85 Ins. + AGST + NVSP	$1,798,505	$1,161,180
Median	NO tools	$1,652,643	$632,967
	%85 Insurance	$2,021,382	$921,698
	%85 Ins. + Agristability	$2,333,363	$1,314,954
	%85 Ins. + AGST + NVSP	$2,360,465	$1,380,080
Warm/Dry	NO tools	$753,016	$213,143
	%85 Insurance	$1,341,684	$737,548
	%85 Ins. + Agristability	$1,527,118	$995,857
	%85 Ins. + AGST + NVSP	$1,569,316	$1,074,173

5.3.2. The Average Net Present Value of Net Farm Income Over Three Decades

Since the planning horizon was quite long (30 years), the results were broken into three time periods (2015-2024, 2025-2034 and 2035-2044) and returns are evaluated within these periods with and without financial management tools. During the first 10 years (2015-2024) period of establishment of the new vineyard, the average year present value of the net farm income was negative, given the establishment costs of the vineyard and no crop insurance coverage. Therefore, the farmers need to be financially stable and prepared to compensate for the non-profitable ten year start-up period. Agristability program is applicable after 10 years of establishment, as the essential of Agristability program for new farming is that at least 2 of 3 years production margin should be positive to calculate Agristability. Therefore, it has not affected the results within the first 10 years for all climate scenarios and conditions. The best net present value of average farm income results for all climate scenarios and CO_2 enhancement conditions were detected between the years 2025-2034, which corresponds to the middle of the planning horizon. The net present value of average farm income was higher, when all financial instruments (Crop Insurance, Agristability) are applied to all climate scenarios and CO_2 conditions. Agristability effect was greater during the 3rd period than the 2nd period. For example; the difference of net present value of average farm income was \$23,106 during the 2nd period and \$32,575 during the 3rd period for Cold/Humid climate scenario with CO_2 enhancement; while the difference was \$29,916 during the 2nd period and \$26,467 during the 3rd period for Warm/Dry climate scenario without CO_2 enhancement. The net present values of average net farm income for the whole period (2015-2044) were \$54,330 for Cold/Humid, \$80,489 for Median, \$61,385 for Warm/Dry scenarios with CO_2 enhancement when all financial management tools were used (Table 26-27).

Table 26: Financial Instrument Effects to Average Yearly Present Value of Net Farm Income Under the Various Scenarios with CO_2 enhancement Condition

Climate Scenarios	Financial Instruments	2015-2024	2025-2034	2035-2044	Total 2015-2044
Cold/ Humid	No Instrument	- $48,774	$120,135	$27,060	$25,100
	85% Ins.	- $22,839	$137,891	$41,193	$44,723
	Agristability	- $48,774	$125,813	$43,492	$31,281
	85% Ins. + Agristability	- $22,839	$143,569	$57,625	$50,904
	85%Ins.+Agristability+NVSP	-$22,226	$144,807	$59,813	$54,330
Median	No Instrument	- $10,720	$142,288	$36,696	$55,088
	85% Ins.	$5,513	$153,339	$43,286	$67,379
	Agristability	- $10,720	$146,140	$55,434	$65,488
	85% Ins. + Agristability	$5,513	$157,191	$62,024	$77,779
	85%Ins.+Agristability+NVSP	-$5,513	$157,809	$64,116	$80,489
Warm/ Dry	No Instrument	- $57,587	$109,112	$23,776	$32,817
	85% Ins.	- $35,066	$132,784	$36,450	$52,082
	Agristability	- $57,587	$117,043	$34,388	$39,543
	85% Ins. + Agristability	- $35,066	$140,715	$47,062	$58,808
	85%Ins.+Agristability+NVSP	-$34,493	$142,071	$49,639	$61,385

Table 27: Financial Instrument Effects to Average Yearly Present Value of Net Farm Income Under the Various Scenarios without CO_2 Enhancement Condition

Climate Scenarios	Financial Instruments	2015-2024	2025-2034	2035-2044	Total 2015-2044
Cold/ Humid	No Instrument	- $64,984	$95,640	$10,831	$13,828
	85% Ins.	- $50,271	$114,081	$25,184	$29,664
	Agristability	-$64,984	$100,305	$29,053	$20,931
	85% Ins. + Agristability	- $50,271	$118,746	$43,406	$36,767
	85%Ins.+Agristability+NVSP	-$49,999	$121,136	$46,697	$42,720
Median	No Instrument	- $49,811	$104,304	$8,803	$21,098
	85% Ins.	- $36,638	$112,235	$16,572	$43,832
	Agristability	-$49,811	$109,410	$31,491	$33,673
	85% Ins. + Agristability	- $36,638	$117,341	$39,260	$56,407
	85%Ins.+Agristability+NVSP	-$36,618	$119,968	$43,135	$62,929
Warm/ Dry	No Instrument	- $67,721	$84,070	$4,966	$7,105
	85% Ins.	- $45,833	$103,328	$16,260	$24,585
	Agristability	- $67,721	$94,728	$20,139	$15,715
	85% Ins. + Agristability	- $45,833	$113,986	$31,433	$33,195
	85%Ins.+Agristability+NVSP	-$44,272	$117,251	$35,219	$41,807

5.3.3. Loss in Net Present Value of Net Farm Income without Financial Management Tools

Tables 29 & 30 clearly demonstrate the positive effect of the use of financial risk management tools on the net present value of net farm income and highlight the importance of using them effectively. The overall results between the years 2015-2044 indicate that the largest losses[19] occur in the without CO_2 enhancement segment, the highest being the Cold/Humid scenario with 75% followed by Warm/Dry with 69%. Finally, Median scenario losses are with 50%. However, the highest loss appears in between 2015-2024, with CO_2 enhancement side, at the Median scenario with 294%. This exceptionally high rate is due to the large number of years within the 2015-24 period with negative reference margins. This is followed by Cold/Humid scenario with 114% over the same time period. The losses are in the range of 26% to 75% during the 30 years period for all climate scenarios and CO_2 enhancement conditions. These results highlight the importance of the use of financial risk management tools.

[19] Loss of potential net present value is measured as the percentage difference between returns with and without adaptation.

Table 28: Reduction on the Net Present Value of Net Farm Income at Different Climate Scenarios, with CO_2 Enhancement

Climate Scenarios		2015-2024	2025-2034	2035-2044	2015-2044
Warm/Dry	No Tools	-$575,870	$1,091,120	$237,760	$753,010
	Full Tools	-$353,528	$1,420,706	$496,395	$1,563,573
	Reduction	$222,342	$329,586	$258,635	$810,563
	% Reduction	63	23	52	52
Median	No Tools	-$107,200	$1,422,880	$366,960	$1,682,640
	Full Tools	$55,130	$1,578,087	$641,164	$2,274,381
	Reduction	$162,330	$155,207	$274,204	$591,741
	% Reduction	294	10	43	26
Cold/Humid	No Tools	-$487,740	$1,201,350	$270,600	$984,210
	Full Tools	-$228,390	$1,448,065	$598,126	$1,817,801
	Reduction	$259,350	$246,715	$327,526	$833,591
	% Reduction	114	17	55	46

Table 29: Reduction on the Net Present Value of Net Farm Income at Different Climate Scenarios, with CO_2 Enhancement

Climate Scenarios		2015-2024	2025-2034	2035-2044	2015-2044
Warm/Dry	No Tools	-$677,210	$956,400	$49,660	$328,850
	Full Tools	-$466,138	$1,172,510	$352,188	$1,058,560
	Reduction	$211,072	$216,110	$302,528	$729,710
	% Reduction	45	18	86	69
Median	No Tools	-$498,110	$1,043,040	$88,030	$632,960
	Full Tools	-$366,482	$1,199,684	$431,451	$1,264,653
	Reduction	$131,628	$156,644	$343,421	$631,693
	% Reduction	36	13	80	50
Cold/Humid	No Tools	-$649,840	$840,700	$108,310	$299,170
	Full Tools	-$504,073	$1,211,356	$466,967	$1,174,250
	Reduction	$145,767	$370,656	$358,657	$875,080
	% Reduction	29	31	77	75

5.4. THE PRESENT VALUE OF NET FARM INCOME BY VARIETY

Table 31 provides the present value of net farm income for each crop with different climate scenarios and conditions. Some crops are not profitable at all under most climate scenarios and conditions i.e. Chardonnay seems to be the most risky crop as it gives a negative income in most scenarios even with the support of the financial risk management tools, except Median scenario Financial risk management tools. On the other hand, Cabernet Franc, Cabernet Sauvignon and Merlot seem to be the most profitable crops under all conditions. Negative present value of net farm income mostly occurred under the Warm/Dry scenario, regardless of the CO_2 enhancements and financial risk management tools. The negative present value of the net farm income ranges from -$284,684 (without CO_2) to -$20,316, which are both without financial risk management tools. The positive side; however, ranges from a minimum of $85,261 to a maximum of $605,488 with the use of Financial risk management tools.

Table 30: The Present Value of Net Farm Income for Each Variety with Various Climate Scenarios and CO_2 enhancement Conditions, with and without Financial Risk Management Tools, 2015-2044

Variety	Financial Risk Management Tools	CO_2 condition	Climate Scenarios		
			Warm/Dry	Median	Cold/Humid
Chardonnay	(-)	With	-$181,558	-$118,112	-$144,231
		Without	-$275,010	-284,694	-$284,325
	(+)	With	-$34,854	$85,261	-$70,449
		Without	-$104,047	-$61,072	-$138,738
Riesling	(-)	With	-$247,389	-$76,950	-$76,037
		Without	-$275,010	-263,480	-$222,041
	(+)	With	-$46,355	$132,561	$140,677
		Without	-$126,420	-$68,811	$15,438
Cabernet Franc	(-)	With	$293,440	$555,432	-$76,037
		Without	$172,708	-263,480	$254,149
	(+)	With	$548,622	$605,488	$497,582
		Without	$401,520	$439,056	$405,718
Cabernet Sauvignon	(-)	With	$293,440	$472,590	$411,779
		Without	$172,708	353,531	$322,835
	(+)	With	$440,303	$532,809	$448,180
		Without	$466,349	$404,571	$368,022
Merlot	(-)	With	$351,243	$407,952	$411,779
		Without	$250,588	286,469	$84,561
	(+)	With	$408,625	$455,996	$380,127
		Without	$298,024	$331,370	$309,618
Pinot Noir	(-)	With	$163,151	$407,952	$210,519
		Without	-$20,316	144,231	$84,561
	(+)	With	$304,708	$538,108	$314,968
		Without	$144,324	$290,743	$238,816

(-) does not include any financial management tools
(+) includes 85% Crop Insurance, Agristability, New Vineyard Support Program

5.5. THE PRESENT VALUE OF NET FARM INCOME BY DECADE AND VARIETIES

The ten-year period 2025-2034 provides the most striking results. Therefore, all of the following examples are chosen from that decade. In terms of negative figures, the Riesling variety in Warm/Dry scenario with CO_2 seems to incur the largest loss with -$349,721 when no financial risk management tools are applied. Even if the financial risk management tools are introduced Riesling again provided negative income within the same period, no matter which scenario is applied. Chardonnay is the second runner up in terms of loss and provides a similar trend to Riesling. The figures for the same decade and scenario are even worse for the without CO_2 case. For Riesling, the maximum loss reaches to -$366,688 and Chardonnay to -$301,800. The overall best performer with the financial risk management tools and CO_2 enhancement applied is Cabernet Franc $321,988 followed by Pinot Noir $320,357 both at the Median scenario. The best performers without the financial risk management tools but with CO_2 enhancement in between 2025-2034 are Cabernet Franc with $323,077 followed by Cabernet Sauvignon with $281,273 both at the Median Scenario. By omitting the financial risk management tools and CO_2 enhancements the best performers are Cabernet Sauvignon with $236,550 followed by Cabernet Franc with $226,098 both at the Median scenario (Table 31-32).

Table 31: Ten-Year Financial Risk Management Tool Effects on The Present Value of Net Farm Income for Each Variety with Various Climate Scenarios with CO_2 Enhancement

Variety	Climate Scenario	2015-2024		2025-2034		2035-2044	
		Financial Risk Management Tools					
		(-)	(+)	(-)	(+)	(-)	(+)
Chardonnay	Warm/Dry	-$223,082	-$193,710	$83,682	$134,807	-$42,158	$26,619
	Median	-$187,848	-$153,179	$112,768	$178,099	-$43,032	$50,517
	Cold/Humid	-$245,898	-$218,710	$85,206	$118,797	-$26,911	$43,734
Riesling	Warm/Dry	-$349,721	-$317,052	$120,158	$216,622	-$17,826	$57,385
	Median	-$287,659	-$250,497	$209,686	$300,104	$1,022	$86,925
	Cold/Humid	-$210,504	-$169,602	$130,795	$227,289	$3,672	$122,368
Cabernet Franc	Warm/Dry	$36,078	$114,395	$215,831	$313,707	$51,532	$124,975
	Median	$144,887	$153,944	$323,077	$321,988	$87,467	$134,541
	Cold/Humid	-$920	$126,709	$220,481	$267,077	$68,794	$133,866
Cabernet Sauvignon	Warm/Dry	$50,218	$77,982	$223,951	$250,185	$99,959	$115,301
	Median	$76,550	$98,872	$281,273	$295,853	$114,767	$142,432
	Cold/Humid	$88,789	$115,454	$232,445	$255,127	$90,545	$112,364
Merlot	Warm/Dry	$38,250	$56,071	$222,828	$246,935	$90,165	$109,897
	Median	$72,707	$92,337	$234,347	$246,351	$100,898	$121,229
	Cold/Humid	$65,255	$85,301	$185,915	$203,620	$86,328	$105,437
Pinot Noir	Warm/Dry	-$117,614	-$80,133	$224,675	$264,652	$56,090	$120,857
	Median	$74,162	$113,649	$261,731	$320,357	$75,838	$109,477
	Cold/Humid	$13,470	$55,295	$179,613	$238,493	$17,436	$68,561

(-) does not include any financial management tools
(+) includes 85% Crop Insurance, Agristability, New Vineyard Support Program

Table 32: Ten-year Financial Risk Management Tool Effects on The Present Value of Net Farm Income for Each Variety with Various Climate Scenarios without CO_2 Enhancement

Variety	Climate Scenario	2015-2024		2025-2034		2035-2044	
		Financial Risk Management Tools					
		(-)	(+)	(-)	(+)	(-)	(+)
Chardonnay	Warm/Dry	-$254,391	-$207,028	$45,409	$105,623	-$66,028	-$149
	Median	-$249,924	-$193,566	$47,140	$120,861	-$81,910	$14,018
	Cold/Humid	-$301,800	-$275,255	$64,705	$130,395	-$47,229	$22,902
Riesling	Warm/Dry	-$366,688	-$332,103	$80,008	$166,310	-$50,517	$44,336
	Median	-$352,176	-$319,904	$135,553	$22,324	-$46,857	$232,365
	Cold/Humid	-$303,576	-$260,599	$121,537	$194,011	-$40,002	$100,900
Cabernet Franc	Warm/Dry	-$5,832	$77,716	$162,085	$251,574	$16,456	$133,866
	Median	$84,382	$81,135	$226,098	$263,994	$50,431	$81,306
	Cold/Humid	-$2,603	$24,526	$210,766	$254,503	$45,986	$98,602
Cabernet Sauvignon	Warm/Dry	$116,896	$139,081	$226,563	$239,337	$78,910	$92,106
	Median	$30,829	$50,010	$236,550	$249,758	$86,152	$108,892
	Cold/Humid	$30,734	$45,840	$208,605	$231,699	$83,496	$107,416
Merlot	Warm/Dry	$1,948	$17,937	$184,050	$198,844	$64,590	$83,362
	Median	$19,081	$35,405	$195,737	$204,040	$71,651	$95,585
	Cold/Humid	$4,421	$19,127	$183,674	$200,176	$71,596	$91,184
Pinot Noir	Warm/Dry	-$162,141	-$130,322	$142,588	$189,214	$6,237	$99,305
	Median	-$30,300	-$4,100	$165,964	$236,743	$8,567	$62,674
	Cold/Humid	-$77,018	-$46,515	$167,113	$249,981	-$5,534	$64,856

(-) does not include any financial management tools
(+) includes 85% Crop Insurance, Agristability, New Vineyard Support Program

5.6. THE NEW VINEYARD SUPPORT PROGRAM PAYMENTS FOR VARIETIES

When the New Vineyard Support Program (NVSP) is applied to the varieties Chardonnay and Pinot Noir, corresponding to 39% of the total crop area, receives 65% of the total support amount (i.e. highest support of $78,316) while Cabernet Sauvignon, covering only 10% of the representative farm, receives the least amount of support (i.e. $120) at the same scenario (Warm/Dry, without CO_2). The periods which are eligible to highest support are 2035-2039 at the Median scenario without CO_2 enhancement condition with $9,508 (for the Chardonnay variety) and 2025-2020 at the Warm/dry scenario without CO_2 enhancement condition (for the Pinot Noir variety) (Table 33).

Table 33: New Vineyard Support Program Payment for Various Grape Varieties Under The Various Climate Scenarios with CO_2 Enhancement Conditions

Variety	5 year Periods	With CO_2 Climate Model Projections			Without CO_2 Climate Model Projections		
		Warm/ Dry	Median	Cold/ Humid	Warm/ Dry	Median	Cold/ Humid
Chardonnay	2020-2024	$0	$0	$0	$0	$102	$1,363
	2025-2020	$4,454	$1,248	$3,315	$7,611	$6,918	$6,478
	2030-2034	$4,846	$3,558	$2,864	$7,411	$7,730	$5,706
	2035-2039	$6,573	$7,216	$3,930	$8,068	$9,508	$5,295
	2040-2044	$3,237	$2,878	$2,513	$3,971	$4,176	$3,067
Riesling	2020-2024	$0	$0	$0	$0	$0	$0
	2025-2020	$0	$0	$0	$0	$0	$0
	2030-2034	$0	$0	$0	$1,259	$0	$0
	2035-2039	$3,954	$3,295	$4,316	$5,536	$5,453	$5,788
	2040-2044	$1,111	$502	$34	$1,887	$1,736	$1,205
Cabernet Franc	2020-2024	$0	$0	$0	$0	$0	$0
	2025-2020	$0	$0	$0	$0	$0	$0
	2030-2034	$0	$0	$0	$1,956	$0	$0
	2035-2039	$4,265	$2,495	$2,814	$6,399	$4,713	$4,313
	2040-2044	$392	$50	$0	$1,675	$1,318	$808
Cabernet Sauvignon	2020-2024	$0	$0	$0	$0	$0	$0
	2025-2020	$0	$0	$0	$0	$0	$0
	2030-2034	$0	$0	$0	$0	$0	$0
	2035-2039	$0	$0	$71	$120	$0	$0
	2040-2044	$0	$0	$0	$0	$0	$0
Merlot	2020-2024	$0	$0	$0	$0	$0	$0
	2025-2020	$0	$0	$0	$0	$0	$0
	2030-2034	$0	$0	$105	$0	$0	$0
	2035-2039	$491	$0	$0	$491	$2,115	$1,908
	2040-2044	$0	$0	$0	$0	$0	$32
Pinot Noir	2020-2024	$2,868	$0	$0	$7,808	$0	$0
	2025-2020	$3,126	$0	$1,740	$8,841	$5,922	$5,079
	2030-2034	$1,130	$1,371	$4,351	$5,572	$5,703	$6,633
	2035-2039	$4,176	$3,660	$5,430	$6,821	$7,004	$6,906
	2040-2044	$1,575	$828	$2,768	$2,890	$2,728	$3,586
Total	**2015-2044**	**$42,198**	**$27,102**	**$34,251**	**$78,316**	**$65,126**	**$58,167**

5.7. Sensitivity Analysis

The discount factor used in the NPV calculation has a great potential to affect the results mentioned above. Those results utilized a 4.00% discount rate to calculate the NPV. The effect of varying the discount rate with each climate scenario on the net present value of the net farm income is shown in Table 35 As the discount rate increases, the NPV of the income stream decreases for each climate scenario. The most notable reduction in NPV was when the discount rate is increased from 4.00% and 6.00% under the best climate scenario of Median with CO_2 enhancement and financial risk management tools. The difference in the present value of the net farm income reached $727,350. The NPV under the worst scenario; i.e. Warm/Dry, without CO_2 enhancement, and No financial management tools, had the smallest reduction of $147,838 in the interest rate of 5.00% and 6.00%.

Table 34: The Net Present Values with Varying Discount Rates Under All Scenarios and Conditions

NPV ($)		Financial Risk Management Tools					
		Without			With		
Discount Rates		4%	5%	6%	4%	5%	6%
Scenarios							
Cold/ Humid	With CO2	$984,511	$708,043	$472,729	$1,817,815	$1,467,767	1,170,335
	Without CO2	$414,869	$214,089	$41,403	$1,161,179	$910,989	$684,405
Median	With CO2	$1,652,643	$1,306,621	$1,011,633	$2,360,465	$1,967,252	$1,633,115
	Without CO2	$632,967	$416,269	$229,273	$1,380,080	$1,127,171	$910,202
Warm/ Dry	With CO2	$753,016	$499,870	$284,606	$1,569,316	$1,241,861	$964,438
	Without CO2	$213,143	$42,149	-$105,689	$1,074,173	$838,712	$636,915

a without: NPVs without any financial instruments

b with: NPVs with max85% crop insurance, agristability, and new vineyard support program

CHAPTER 6

CONCLUSION AND RECOMMENDATIONS

This study evaluated the economic impact of climate change on a representative vineyard in the Niagara Peninsula. The main objectives were a) to develop a Net Present Value model for a representative vineyard for a 30-year planning horizon; b) to evaluate the impacts of various climate scenarios, C02 enhancement, and changing market conditions on the present value of net farm income, output, crop acreage, and economic vulnerability of the representative vineyard; c) to identify and assess the role of Financial Risk Management Tools such as Crop Insurance and Agristability program; d) to develop a new policy i.e. New Vineyard Support Program for the Niagara Peninsula representative farm as a supplement to existing financial management tools.

Within this context, the most recent meteorological data retrieved from the stations is the period of 1971-2000 as the historical reference period, and 2015-2044 for the future time period. Three future climate scenarios (Warm/Dry, Median, Cold/Humid), two combinations of conditions (with and without CO_2); on six grape varieties Chardonnay, Riesling, Cabernet Sauvignon, Cabernet Franc, Merlot, and Pinot Noir were considered. While the reference crop yield was calibrated and validated manually, the CropSyst programme proved to output a higher yield results in simulated cultivar than reference/historic cultivar. Yields of the six crops were simulated for the future period using CropSyst v.4.13.09; Costs of production and prices of the crops were projected using Monte Carlo simulation. A 30-year Net Present Value (NPV) model was applied to the study site using the simulated yields, projected costs and prices, insurance options, and other parameters; i.e. discount rate was used to evaluate the economic impact of climate change on the representative vineyard.

6.1. MAIN FINDINGS OF THE STUDY

The main findings indicate that the present value of net farm income, output, as well as economic vulnerability and adaptation, varied depending on the climate scenario (Warm/Dry, Cold/Humid, or Median) and the combinations of conditions (with or without C02 enhancement). The direction (negative or positive) and magnitude of the impacts were affected by the grape variety that was grown (2015-2044). The climate change impacts were found within the climate models. It was found that the impacts of climate scenarios were exacerbated by CO_2 conditions, and these varied by grape variety. For instance, Riesling, Pinot Noir and Chardonnay had the largest number of planted acres while Merlot, Cabernet Franc, and Cabernet Sauvignon had smaller number of planted acres. Consistently Red grape variety yields (ton/acre), except Pinot Noir, were consistently greater than the yields (ton/acre) of the white grape varieties. But the production of white grape varieties was greater than red grape varieties except Pinot Noir. Furthermore, it is worth noting that the allocation of land would affect the results. Some of the grape varieties produced a negative net present value of net income alone, but the total present value of net income was always positive. However, the growers may keep the non-profitable species in order to mix them with other varieties to produce the sought after being tasted by the consumers.

CO_2 enhancement has a considerable effect on yield under each climate scenario. Under the worst climate - Warm/Dry - scenario with the absence of CO_2 enhancement; red wine grape varieties (Cabernet Franc, Cabernet Sauvignon, Merlot and Pinot Noir), which are known as warm climate varieties, had a higher relative economic return per acre than white wine grape varieties (Chardonnay, Riesling, Cool climate types). Chardonnay and Riesling were the only crops that experienced a negative net farm income as being insensitive to any climate scenarios and conditions. The climate scenario that generated the largest present value of Net Farm Income per acre was the Median climate scenario with CO_2 enhancement for all varieties. It is clear that CO_2 enhancement affects crop-growing phenology in a positive way. The Median climate scenario's temperature, precipitation and solar radiation values were found more suitable than the other climate scenarios for wine-grape variety growth. Wine-grape varieties grow in moderately warm climates. The dry condition was not good for all of the selected crops. That is why the Median climate scenario, with CO_2 enhancement had the greatest present value of net farm income than the Warm/Dry scenario.

The revenue from the lower yields of the Chardonnay and Riesling varieties were not large enough cover the rising costs of production although their prices follow an upward trend. This made these crops unprofitable under most of the climate scenarios and conditions. Within a span of 30 years and the lack of production within the first four years of Chardonnay, this type produced a negative net present value of net farm income for 15 years under the Warm/Dry scenario, 14 years under the Median, and finally 12 years under the Cold/Humid scenario with CO_2 enhancement. Within the same conditions, Riesling followed with 12 years, 10 years, 8 years respectively. On the other hand, the total revenue from Cabernet Franc and Merlot compensates for the rising cost of production over time. The increased revenue came from higher yields and prices. Cabernet Franc and Merlot seems to be the most profitable varieties under all climate scenarios and conditions.

The combination of six grape varieties was found to reduce net farm income. Replacing Chardonnay and Riesling with Merlot and Cabernet Franc would increase the present value of net farm income than the initial allocation of acres. Merlot and Cabernet Franc would take advantage of the climate change in the region. Each variety's requirements will differ under future climate scenarios and CO_2 enhancement conditions. But it needs to be considered that although financially non-viable, white species such as Riesling is particularly in demand by some consumers due to its specific taste. As the wine sector is too sensitive to the taste factor, a price increase or financial tool leverage may be applied to such species.

The same factors making the producers vulnerable encourage for managing their financial risks and ensure their crops. Some scenarios and conditions make producers more prone to suffering losses. The importance of the various financial risk management programs was emphasized by the results. Without such financial risk managements programs, the loss of potential income would be too big for some scenarios and conditions in this region. The implication of the results was that this region would miss opportunities to earn more net farm income, to compensate for the establishment cost in the near future, if it fails to adapt financial risk management tools. These tools, as adaptation options, would help absorb the yearly negative impacts of variability of net farm income due to changes in climatic and economic conditions, and stabilize income. However, these tools do not necessarily ensure that producers would be totally free of risk. In other words, if climate change and subsequent economic conditions lead to consecutive years of large losses and reduced levels of production activities or that turned reference margins negative, benefits from insurance programs would also drop low to eventually none. The efficient use of their financial risk management tools will allow producers to reduce their economic vulnerability and improve their financial position. This would provide some level of flexibility in their choice of short- term adjustment and long-term net farm income, and help them remain in profitable production.

The present value of net farm income had been changed depending on climate scenarios, conditions, and financial management options. The results highlight the importance of CO_2 concentrations. The Niagara Region would benefit from the introduction of a New Vineyard Support Program, in order to take advantage of opportunities that would arise along with climate change. Climate change could have a negative impact on Chardonnay and Riesling productivity, and eventually could lead to higher prices as well as lowering competition. That is why, producers in this region would be better off if they are pre-informed on the agronomic, technological and financial tools to prevent losses. Accessing long-term projections of climate change and economic variables affecting their production would assist them in making their production management decisions. The major aim should be protecting grape growers of Ontario and help them design strategies that could boost their productivity.

6.2. LIMITATIONS OF THE STUDY

There are some limitations to this study, which are worth mentioning:

1. The future yield data generated with CropSyst was based on the assumption that the single limiting factor was "CO_2 enhancement". In reality, water availability, soil fertility, and other problems at the sites have an impact on the yield. Production yields of vineyards with drip irrigation system were not considered in this study;
2. The NPV model does not include borrowing i.e. utilizing credit; while in reality farmers are engaged in such financial transactions. It is also assumed that growers have 100% ownership of the farm. Hence, the results do not estimate the impacts of how differences in owner equity could affect the NPV calculation;
3. The projections of the economic variables, i.e. prices, cost, etc. were based on the data compiled by the Grape Growers of Ontario. These seem to be the best approximations of what producers would have to pay/receive in the future for their crops. However, the data from a professional market analysis report may lead to different results;
4. The cost of production data was only available for the year 2009. Therefore, Monte Carlo simulation could not be applied to the cost of production. If there were more year data, the Monte Carlo simulation could have been applied for healthier results.

6.3. FUTURE RESEARCH

This study provides results on the impact of climate change on the Niagara Peninsula using some basic assumptions. This research could be enriched by including the following:

1. Land allocation and grape variety mix were determined exogenously from the model. This allocation was placed in a year with one of the model and was not changed over the duration of the full time period. The analysis would be enhanced if land and variety mix could be determined endogenously. A mathematical programming approach such as dynamic modelling could provide an optimal solution.
2. Grapevines are perennial crops and could remain productive for several years and even decades. The future period could be selected longer than the present study (30 years) and could be divided into two periods (of 30 years each). However, some varieties have shorter lifespans when winter temperatures are colder. The rotation as an adaptation option could be generated during the second period according to first period results. Then, dynamic (two-period) programming approach can also be applied to estimate the NPVs.

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APPENDIX

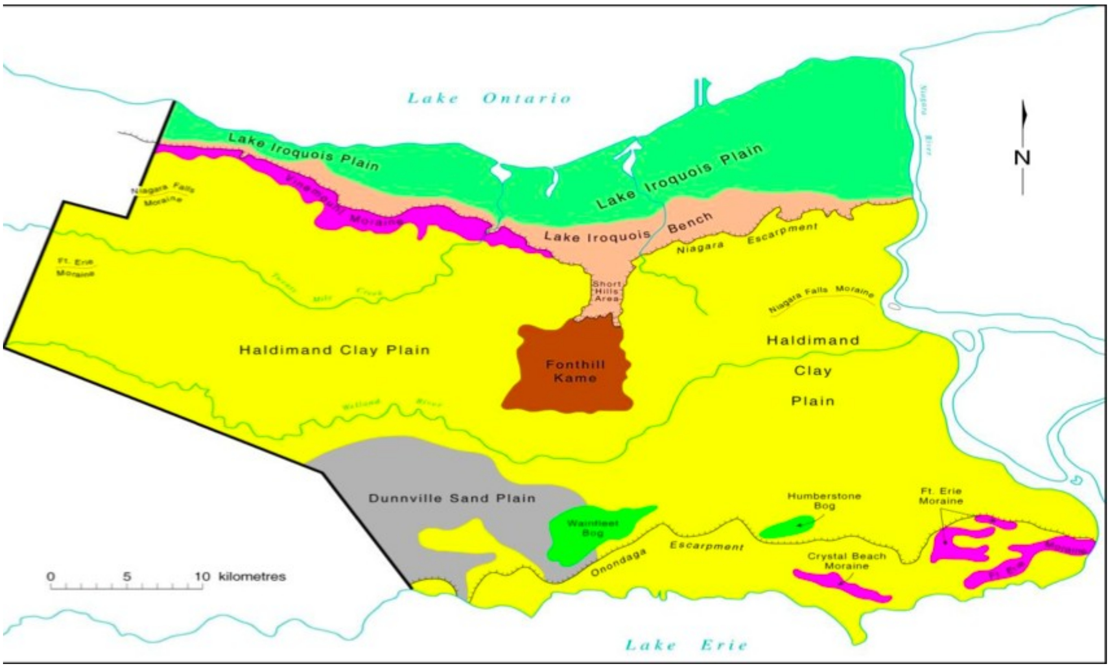
Annex 1: Relative Location of Niagara Peninsula under Grape and Tender Climatic Zones of Canada

Source: Shaw, A.B. "Pelee Island and Lake Erie North Shore, Ontario: A Climatic Analysis of Canada's Warmest Wine Region", 2010

Annex 2 Map indicating the Niagara Region of Canada, located between the Great Lakes of Ontario and Erie

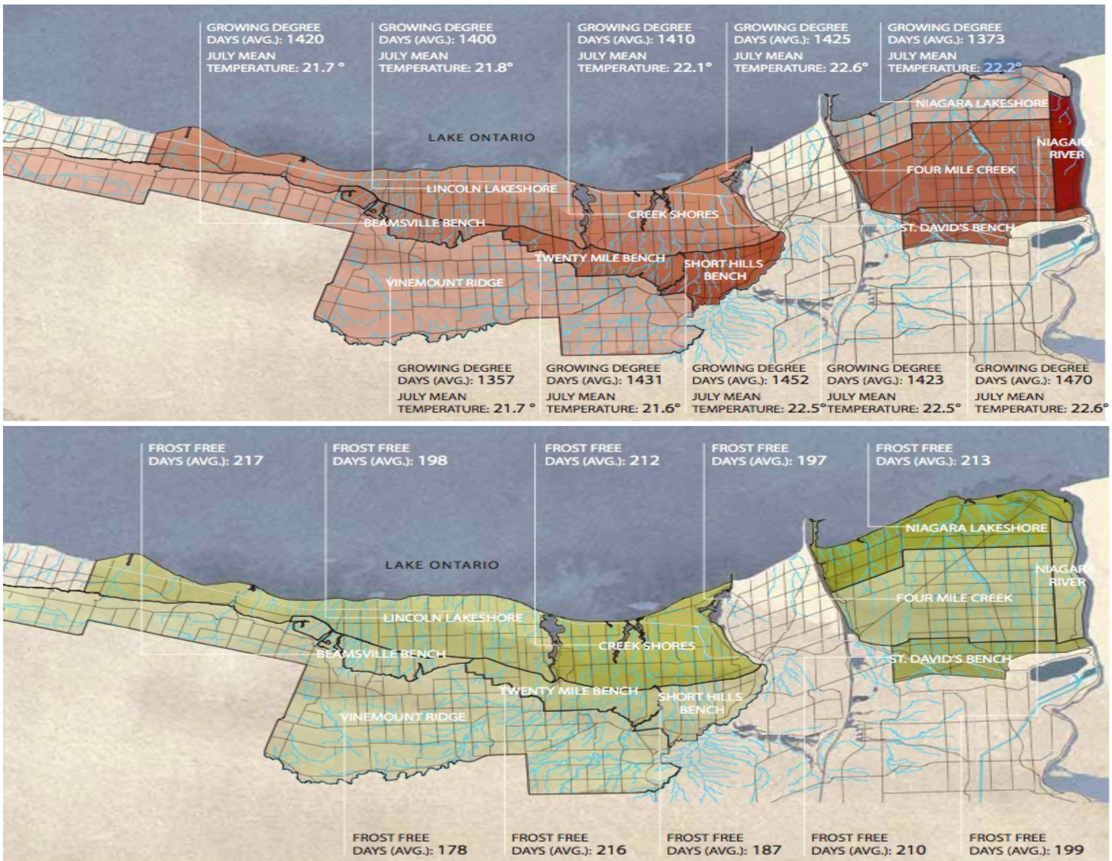
Source: Don Cyr [a], Martin Kusy & Anthony B. Shaw[1]

Annex 3 Physiographic areas of the Niagara region



Source: 2013 VQA Reporting

Annex 4 Growing degree days and July mean temperature, Precipitation, Frost free days



Source: VQA Ontario

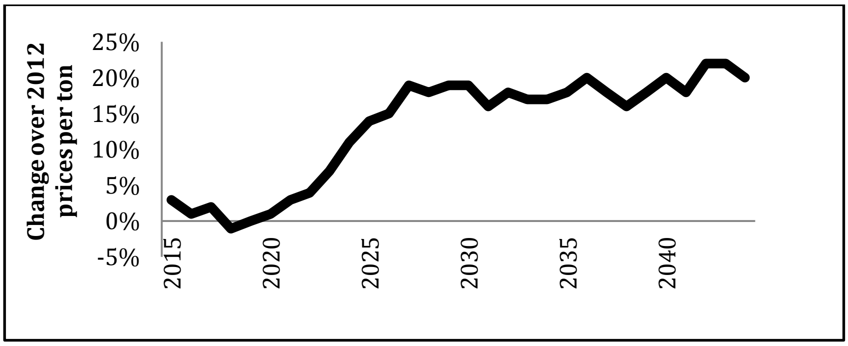
Annex 5: Differences between Brix Level and Grape Prices

CHARDONNAY			RIESLING			CAB.SAUV.			CAB.FRANC	MERLOT			PINOT NOIR		
BRIX	%of BASE	$/TONNE	BRIX	%of BASE	$/TONNE	BRIX	%of BASE	$/TONNE	$/TONNE	BRIX	%of BASE	$/TONNE	BRIX	%of BASE	$/TONNE
20.5	97.50%	$1,429.00	18.7	89.50%	$1,409.54	20.9	97.00%	$1,300.00	$1,300.00	21.3	96.50%	$1,827.71	20.5	97.50%	$1,884.68
20.6	98.00%	$1,437.12	18.8	99.00%	$1,416.69	21	97.50%	$1,828.13	$1,828.13	21.4	97.00%	$1,837.18	20.6	98.00%	$1,894.34
20.7	98.50%	$1,444.41	18.9	99.50%	$1,423.85	21.1	98.00%	$1,837.50	$1,837.50	21.5	97.50%	$1,846.65	20.7	98.50%	$1,904.01
20.8	99.00%	$1,445.31	**19.0**	**100.00%**	**$1,431.00**	21.2	98.50%	$1,846.68	$1,846.68	21.6	98.00%	$1,856.12	20.8	99.00%	$1,913.67
20.9	99.50%	$1,451.47	19.1	100.50%	$1,438.16	21.3	99.00%	$1,856.25	$1,856.25	21.7	98.50%	$1,865.59	20.9	99.50%	$1,923.34
21.0	**100.00%**	**$1,459.00**	19.2	101.00%	$1,445.31	21.4	99.50%	$1,865.63	$1,865.63	21.8	99.00%	$1,875.07	**21.0**	**100.00%**	**$1,933.00**
21.1	100.50%	$1,466.30	19.3	101.50%	$1,452.47	**21.5**	**100.00%**	**$1,875.00**	**$1,875.00**	21.9	99.50%	$1,884.53	21.1	100.50%	$1,942.67
21.2	101.00%	$1,473.59	19.4	102.00%	$1,459.62	21.6	100.50%	$1,884.38	$1,884.38	**22.0**	**100.00%**	**$1,894.00**	21.2	101.00%	$1,952.33

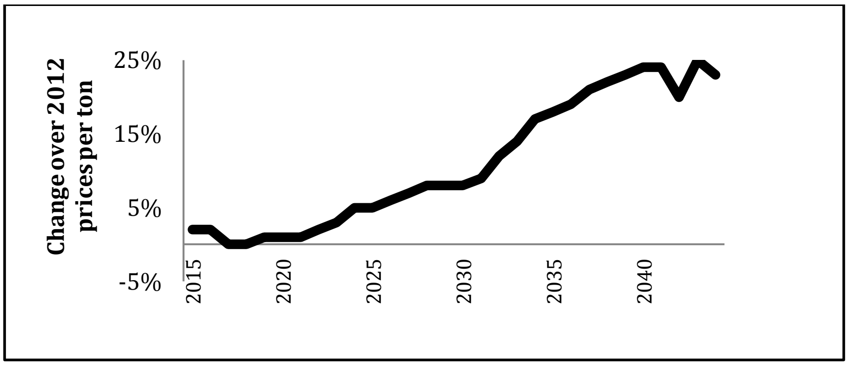
Source: Grape Growers Ontario 2013 Report

ANNEX 6 Panel A-H: **Trends in Observed and Projected Producers' Prices and Costs**

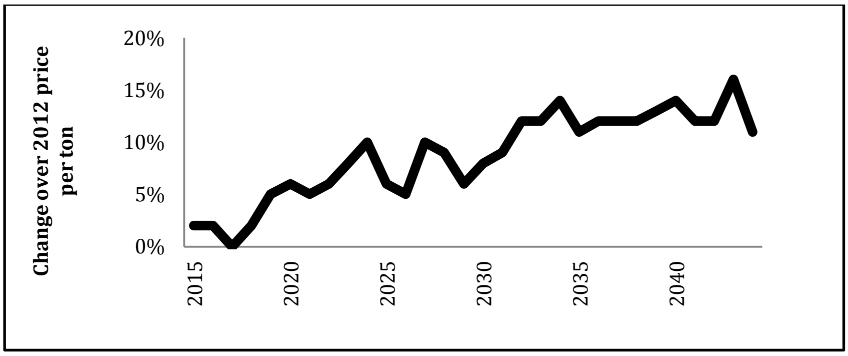
Panel A: Simulated in Average Producers' Prices of Chardonnay 2015-2044



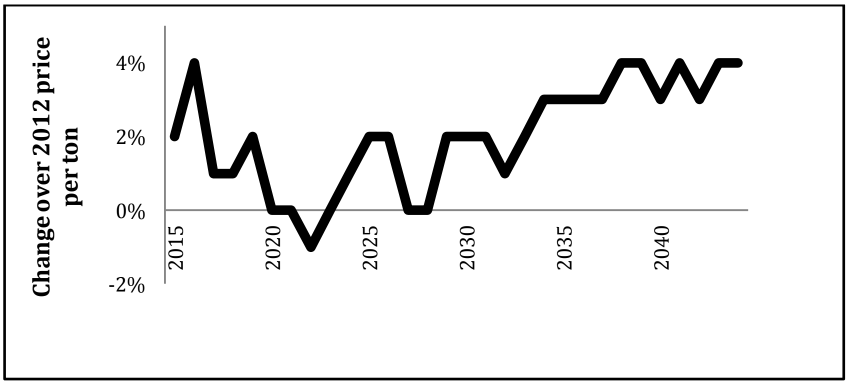
Panel B: Simulated in Average Producers' Prices of Riesling 2015-2044



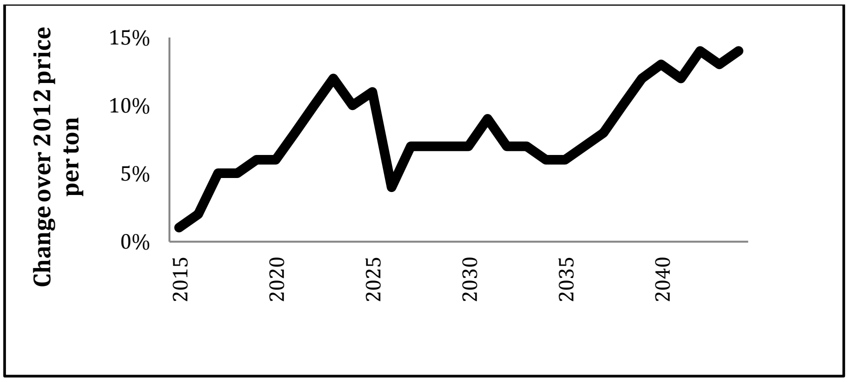
Panel C: Simulated in Average Producers' Prices of Cabernet Franc 2015-2044



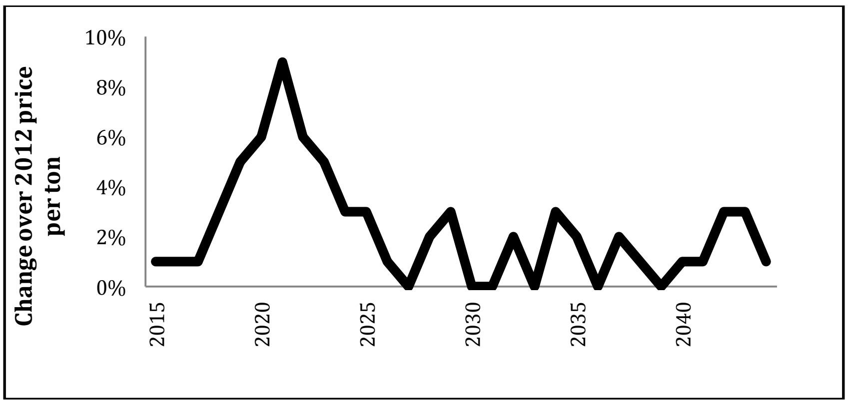
Panel D: Simulated in Average Producers' Prices of Cabernet Sauvignon



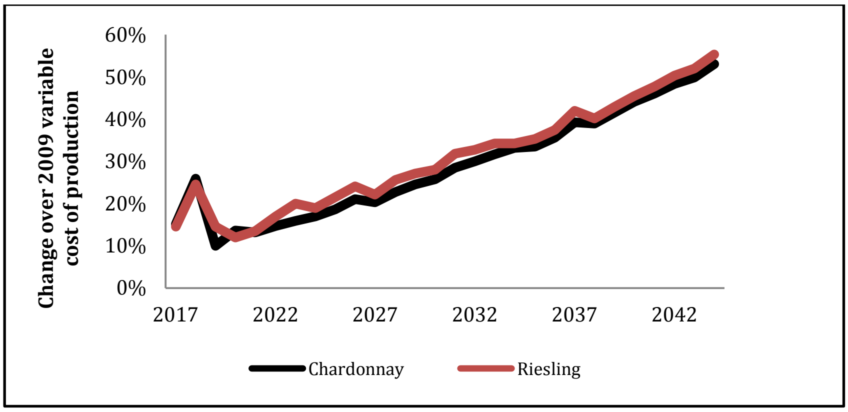
Panel E: Simulated in Average Producers' Prices of Merlot 2015-2044



Panel F: Simulated in Average Producers' Prices of Pinot Noir 2015-2044,



Panel G: Simulated variable cost in the cost of production for White varieties



Panel H: **Simulated variable cost in the cost of production for Red varieties**