THE IMPACT OF CLIMATE CHANGE ON THE UNITED STATES WHISKEY INDUSTRY

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ABSTRACT

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Climate change is one of the most pressing issues of our time and will impact the lives and livelihood of billions of people around the world. As the Earth's climate continues to warm, the whiskey industry will need to acknowledge and adapt to the challenges that climate change will bring. While other alcoholic beverage industries have already reckoned with the effects of climate change, the American whiskey industry has been relatively insulated. This is in part due to the lack of government regulation and having access to a large geographic area with ample resources. This thesis reviewed literature regarding climate change, whiskey, and the intersection of the two. Then, the cognac and beer industry were investigated to examine the severity of climate change's effects on comparable industries. Next, interviews with five American whiskey distillers provided data on areas where the industry would be impacted the most. Qualitative data from the interviews were coded to derive five main themes: climate change's impact on grain variety, whiskey aging, wood used for barrels, freshwater access, and adaptation methods. Finally, adaptation recommendations were provided for the distilleries based on the literature review and data from the qualitative interviews to mitigate the adverse effects of climate change on the American whiskey industry.

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INTRODUCTION

"We are the first generation to feel the effect of climate change
and the last generation who can do something about it."

- Barack Obama, Former United States President

Whiskey is a combination of expertise, patience, and love. An indulgence for some, a vice for others, and a luxury for all, whiskey has become a symbol of friendship, an expression of celebration, and a moment of respite in a persistent world. A medium through which individual expression is apparent, the seemingly uniform brown liquid transforms into a world of unique characteristics that concludes with a warm embrace for all who dare. To many, whiskey is a strong alcohol spirit with an unapproachable flavor profile that is enjoyed by "others." But to some, whiskey is a delicate process, nurturing a thoughtful mixture of grains through a fermentation, distillation, and aging process that presents its reward as a comforting reminder of the simple pleasures in life. The wisps of aroma captivating the nose, the flavors intimately meeting the palate, the robust heat rushing through the chest – these are the senses that greet anyone brave enough to acquire the taste of the "water of life."

Originating from Scotland in the 1400's, whiskey's popularity surged in the following centuries as people from all around the world took notice of its allure. The love for the distilled spirit has exploded in recent years, where ballooning demand meets dwindling supply as whiskey-lovers search for bottles of their favorite liquor that first entered the barrels for aging 12 years prior. Due to the nature of the aging process, whiskey fanatics appreciate the patience that is required to develop the complexities that come with age in older whiskey. As whiskey ages for four, eight, twelve, eighteen, even twenty-three years plus, the contents of the barrels bring us memories of a generation past. A drink that aged alongside us over the previous decades of our lives, leading up to the current moment where it could finally be enjoyed. Yet, the aging is not so simple. The whiskey enters a delicate dance with the barrel that surrounds it as temperature fluctuations push the whiskey deeper into the pores of the wood, extracting flavor and color that make the liquid so distinguishable to many. As the spirit sits in a barrel, seemingly subject to the forces of nature, its environment is constantly changing. The very hands that brought whiskey into this world also bring changes to the atmosphere, slowly altering the climate which the whiskey intimately interacts with. Without knowledge, the whiskey dances to the beat of its surroundings, as its composition and flavor begin to adjust to the ebb and flow of the terroir around it. That is the duality of whiskey: the unique experience that each barrel provides is both its beauty and its curse, never to be exactly replicated again. As climate change continues to loom, the whiskey industry could be blindsided if it is not careful.

This thesis will examine the impact that climate change will have on the American whiskey industry. Specifically, climate influence on the whiskey-making process and adaptation methods to the effects of climate change will be explored. First, a literature review of climate change will provide insight into the general effects of climate change. The whiskey-making process will also be examined to inform how climate change may influence the whiskey industry. To gain perspective from those familiar with the industry, distilleries across Kentucky and Texas are interviewed about how climate currently affects their whiskey-making process, how they foresee climate change impacting the industry, their experience with climate variability, and potential adaptations to the effects of climate change. Thematic analysis was conducted from the qualitative data to generate five key themes regarding the intersection of climate change and whiskey. Based on the themes from the interviews and literature review, the impact of climate change on whiskey will be examined and adaptation recommendations will be proposed.

As climate change becomes more severe, it will have an impact on the grain used for whiskey, the whiskey aging process, the wood used for whiskey barrels, and access to fresh water. Climate change will also impact how whiskey will be made as potential governmental regulations and shifting consumer preferences will force distilleries to move towards more environmentally sustainable practices. The goal of this thesis is to investigate the risks that climate change will pose to the American whiskey industry and provide potential adaptation methods to mitigate these challenges.

PART II: BACKGROUND

I. Introduction to Climate Change

Climate is the prevailing weather condition in an area over a long period of time, and the Earth's climate is an aggregate of all the climates around the world. As the sun heats the Earth, the atmosphere and the ocean circulate to even out the heating imbalances. This is known as the Earth's heat engine (Lindsey, 2009). The heat is distributed from the equator towards the poles and from the surface of the Earth back to space. There are gases that trap heat in the atmosphere, which are referred to as greenhouse gases.

Over the last 650,000 years, there have been seven cycles of glacial advance and retreat. Most of the climate change in the past can be attributed to small changes in the Earth's orbit, which varies the amount of solar energy the Earth receives (NASA, n.d.). According to the Intergovernmental Panel on Climate Change (IPCC), warming of the climate system is unequivocal, and many of the changes in the recent century are unprecedented. The period from 1983 to 2012 was likely the warmest 30-year period of the last 1400 years in the Northern Hemisphere, and data suggests that the globally averaged combined land and ocean surface temperature from 1880 to 2012 increased by 0.85°C (IPCC, 2014). A comparison based on atmospheric samples contained in ice cores provides evidence that carbon dioxide has increased since the Industrial Revolution. Figure 1 shows that atmospheric carbon dioxide has not exceeded 300 parts per million over the last 800,000 years. The graph also reveals that atmospheric carbon dioxide first exceeded 300 parts per million in 1950 and has surged to over 400 parts per million today.

This warming is primarily explained by the increase in anthropogenic greenhouse gas emissions. Compared to the pre-industrial era, levels of anthropogenic greenhouse gas emissions are higher than ever because of economic and population growth (IPCC, 2014). As a result, the atmospheric concentration of carbon dioxide, methane, and nitrous oxide is unprecedented when compared to the last 800,000 years and is "*extremely likely* to have been the dominant cause of the observed warming since the mid-20th century" (IPCC, 2014).

In the United States, there are six primary sources of greenhouse gas emissions: transportation, electricity production, industry, commercial and residential, agriculture, and land use and forestry (EPA, 2018). Transportation represented 28.2% of 2018 greenhouse gas emissions, generating the largest share from primarily burning fossil fuels in vehicles. Of the fuels used for transportation, petroleum-based fuel (mainly gasoline and diesel) accounted for over 90%. Electricity production represented 26.9% of 2018 greenhouse gas emissions, with 63% of our electricity coming from burning coal and natural gas. Industry represented 22%, commercial and residential 12.3%, agriculture 9.9%, and land use and forestry 11.6%. In 2018, the United States emitted over 6.677 billion metric tons of carbon dioxide equivalents, representing an overall growth of 3.7% since 1990 (EPA, 2018). In a global context, the United States was the second highest emitter of carbon dioxide at 15%, behind only China at 30%.

Global warming has already had a tangible impact on the environment. Average temperatures are warming, sea levels are rising, glaciers are shrinking, heat waves and droughts are more intense, agricultural patterns are changing, and more. If emission trends continue, global warming is likely to reach 1.5°C above pre-industrial levels between 2030 and 2052 (IPCC, 2018). When compared to present-day warming, climate models project robust differences in regional climate temperatures between 1.5°C to 2°C. Some potential differences include an increased mean temperature in most land and ocean regions, hot extremes in most inhabited regions, heavy precipitation in several regions, and probability of drought and precipitation in several regions (IPCC, 2018). Land temperature extremes are projected to warm more than the mean; for extreme hot days in mid-latitude, temperatures will increase by up to approximately 3°C at global warming of 1.5°C and 4°C at global warming of 2°C. For extreme cold nights in high latitudes, temperatures will increase by up to approximately 4.5°C at global warming of 1.5°C, and 6°C at global warming of 2°C (IPCC, 2018). The frequency of hot days is also projected to increase in most land regions.

Warming of 1.5°C and above also poses risks to health, livelihoods, food security, water supply, human security, and economic growth. Global warming is projected to negatively impact human health. With increased temperatures, heat-related morbidity and mortality will increase. Risks from some vector-borne diseases, such as malaria and dengue fever, will increase along with shifts in the diseases' geographic range. Furthermore, vulnerable and disadvantaged populations will be disproportionately impacted by warming. Regions dependent on agriculture or coastal livelihoods bear the highest burden, and poverty is likely to be exacerbated in some populations (IPCC, 2018).

Our resources will also be impacted. Warming of 1.5°C to 2°C will lead to a reduction of yields in maize, rice, wheat, and potentially other cereal crops. The effects of climate change are not necessarily negative in all regions. In regions where growing seasons are limited by colder weather, global warming can extend the growing season. Drought tolerant crops also benefit from warming. Yields of sorghum have increased by 0.7% in sub-Saharan Africa and 0.9% yearly in western, southern, and southeastern Asia due to climate shifts since 1970 (Ray, 2019). While specific crop yields have increased in some regions, global production of staples such as rice and wheat are decreasing at an aggregate level; it is estimated that climate change is reducing global rice yields by 0.3% and wheat yields by 0.9% on average per year (Ray, 2019).

Many aspects of making whiskey are heavily influenced by climate, from growing the grains to aging the distillate in oak barrels. The whiskey industry will not escape the sweeping impacts of climate change, and it is important to examine which parts of the whiskey-making process will be most susceptible to risks.

II. Introduction to the American Whiskey Industry

Whiskey is a distilled alcoholic spirit made from a recipe of fermented grains. Numerous grains can be used, but the most common are corn, barley, rye, and wheat. After distillation, the product is aged in wooden barrels to produce the final product. While whiskey is a classification of alcohol with different types, the unifying characteristics are the fermentation of grains, distillation, and aging in wooden barrels. In the United States, many different types of whiskey are produced, including bourbon, Tennessee whiskey, rye whiskey, and American whiskey (Whiskey Advocate, 2017). However, bourbon is the most recognized.

Bourbon is a type of whiskey that needs to meet five additional criteria to be called "bourbon." The first criteria is that the bourbon must be made in the United States. While 95% of the world's supply of bourbon is from Kentucky, it can be made in any state (Siemens, 2015). The second criteria is that the barrels in which bourbon ages must be new, charred, oak barrels. Some whiskeys are aged in barrels that have already aged other whiskies or other spirits to impart flavor, but to be classified as bourbon, the barrels must be new. Charring the barrel means that the inside of the barrel is exposed to flames, which interact with compounds in the wood such as hemicellulose and lignin to impart flavor to the whiskey during aging. When hemicellulose is exposed to high levels of heat, it breaks down into wood sugars that impart the characteristic brown sugar, caramel, or toffee flavors (Bell, 2016). Similarly, lignin imparts the vanilla flavors found in bourbon. The third criteria is that the mash bill (recipe of grains used) must be over 50% corn. The fourth criteria is that the whiskey cannot enter the barrel at higher than 125 proof and cannot be bottled at less than 80 proof. Proof is a measure of the ethanol content in an alcoholic beverage and is defined as twice the percentage alcohol by volume (ABV). Thus, the distillate cannot enter the barrel to be aged higher than 62.5% ABV and cannot be bottled at less than 40% ABV. Because water evaporates during the aging process, making the contents in the barrel more concentrated, the end product that enters the bottles is commonly diluted with water. The fifth and final criteria is that only water can be added to reduce the proof of the alcohol, when necessary. While color and flavor may be added to other whiskeys, only water can be added to bourbon.

In 2020, the United States whiskey and bourbon industry generated over $4.3 billion in revenue, with an annual growth of 5.6% from 2015-2020. The industry has grown tremendously, increasing from revenue of $1.8 billion in 2003, and projected to hit $4.7 billion in 2025. The top three players are Brown-Forman, Beam Suntory, and Sazerac Company, which hold 33.2%, 17%, and 9.4% market share, respectively (Lombardo, 2020).

Generally, distilleries control the process of making whiskey, from choosing the grains that go into the mash bill to bottling the final product. For the most part, the equipment that distilleries use is the same. Thus, the differentiating factor for whiskey production comes down to the inputs to the process: the grains, the yeast strains, the barrels, and the storage conditions (“How Bourbon is Made”, n.d.). First, a distillery chooses its recipe for the grain mixture. For bourbon, the recipe must be majority corn (>50%) and for rye, the recipe must be majority rye. An example mash bill could consist of 75% corn, 20% rye, and 5% malted barley. The grains are ground and stored separately. Traditionally, fresh spring water is used for whiskey production so the starch in the grain can be cooked and the developing sugars extracted ("How Bourbon is Made", n.d.). If there is no spring water, demineralized/deionized water can be used. Then, the mash bill is cooked at a temperature to convert starch to sugar and is cooled down before adding yeast. During this process called fermentation, yeast converts sugar into alcohol and carbon dioxide and creates a beer with an ABV of approximately 8% to 10%.

Next, the beer enters a process called distillation. Most distilleries use column stills, which allow for continuous distillation to occur. These stills are cylindrical in shape with a height of five to 20 meters and have different levels within the still. The beer is funneled into the still in the middle position and heated from the bottom; this creates two opposite flows. The liquid flows downwards through tubes, while the evaporated gas (alcohol vapors) rise to the top through holes. The alcohol vapor is collected at the top and extracted, while the water and grain particles that accumulate at the bottom are processed into animal feed or used again in the fermentation process. Then, the alcohol vapor is led into a machine called the condenser, which cools and liquifies to raw whiskey, called "white dog" ("How Bourbon is Made", n.d.).

Then, the raw whiskey is transferred into barrels made from American white oak, which typically hold approximately 53 gallons (about 200 liters) each. These barrels are stored in warehouses, with each distillery free to choose its own barrel storage strategy. Typically, a warehouse has multiple floors with various levels, with each level experiencing differing climates. The barrels at the top experience higher temperatures during the summer, while the barrels at the bottom stay cooler. To be labeled as "straight whiskey," the whiskey must be aged for at least two years but can be aged for up to decades. After aging is done, the whiskey is finally poured out of the barrels, filtered or unfiltered, and bottled for sale.

Climate change will likely impact at least four crucial components of the whiskey-making process: the grain production for the mash bill, the wood supply for barrels, the aging process for the whiskey, and the water used throughout the whiskey-making process. This section serves to investigate how climate change has, and potentially will affect these components.

III. The Impact of Climate Change on Grain Yields

The four primary grains in American whiskey-- corn, rye, barley, and wheat-- are impacted differently by climate change.

Corn

Corn is the main ingredient in bourbon and the most important grain in the American whiskey industry. Corn is a cereal plant that originated in the Americas and is one of the world's most widely distributed food crops. Besides whiskey production, corn is used for livestock feed, human consumption, and biofuel. Corn has spread to all areas of the world suitable for cultivation, ranging from 58° N latitude in Canada and Russia to 40° S latitude in South America (Brittanica, n.d.). There are many different classifications of corn. The most popular type is yellow field corn, which is also referred to as dent corn due to the shape of the kernel. Whiskey is primarily made with this yellow field corn that is typically referred to as yellow dent No. 1 or No. 2, which identifies the U.S. Department of Agriculture's quality grade (Kuta, 2020). Because of the many varieties of corn, there is the potential to explore whiskey made with other varieties of corn.

Climate change could potentially result in significant yield decreases for the staple food crop. The optimal growth temperature for corn ranges from 25-33°C during the day and 17-23°C during the night, with a mean seasonal optimal growing temperature of 17-23°C (Neild, n.d.).

Corn can still grow between the range of 5-35°C, and can survive brief exposures to adverse temperatures of below 0°C and above 45°C (Neild, n.d.). One study projects that with increasing global mean temperatures, mean corn crop yields will decline, and the coefficient of variation will increase as the variability in yield will be more volatile (Tigchelaar, 2018). The study also notes that “for the top four maize-exporting countries, which account for 87% of global maize exports, the probability that they have simultaneous production losses greater than 10% in any given year is presently virtually zero, but it increases to 7% under 2°C, warming and 86% under 4°C warming” (Tigchelaar, 2018). The implications of climate warming on corn production extend beyond whiskey. An instability in global grain trade and prices will affect the roughly 800 million people living in poverty who are disproportionately affected by price increases.

The impact of climate change on corn production can also be felt in the United States, especially in a region named the Corn Belt. This region, comprising western Indiana, Illinois, Iowa, Missouri, eastern Nebraska, and eastern Kansas, accounts for over one third of the global supply of corn (Aronsohn, 2019). Warming in the Corn Belt has resulted in warmer winters over the past 30 years, which can lead to overwintering of pests, and warmer summers, which can lead to an increased disease pressure on the crop (Arritt, 2016). Rising overnight temperatures during the growing season can also stunt the growth of corn; “Increasing frequency of warm overnight temperatures has reduced corn production in southern areas of the Corn Belt over the last 10 years” (Todey, 2014). Levels of precipitation have also fluctuated over the past six decades. The average annual rainfall for most of the Midwest has increased, around one to two inches per year (Arritt, 2016). Contextualized, this is a 5-10% increase of the average rainfall over the entire region, which is mostly attributed to the change in heavy rainfall. Over the last 50 years, the Midwest has seen a 50% increase in the number of days with rainfall over four inches, which is a statistically significant increase (Arritt, 2016). Most of the increase in rainfall has increased during the warmer summer months, with less fluctuation during the winter months.

Two studies have conflicting predictions about the changing levels of precipitation for the Midwest in the future, but both conclude that the impact of climate change on precipitation will be negative for corn production in the Corn Belt. The first study, conducted by Arritt, used a procedure called “downscaling,” or using a finer-scale climate model to add details to the coarse global model results, to predict precipitation levels. The calculations predict that over the next 30 years, average precipitation will increase slightly, mainly in the winter and spring (Arritt, 2016). This is because the air is predicted to warm, which then can hold more moisture. The projected increased rainfall levels and frequency have negative implications, leading to increased soil erosion, flooding, and other structural damage (Todey, 2014). Thus, preparation from farmers would be prudent. Installation of subsurface drainage tiles has increased in recent years. These installations, combined with covering crops during heavy rainfall, can help prevent erosion and control nutrient runoff. The study also notes that the proposed projections differ from the global climate models, which predict that the Midwest will see a decrease in rainfall in the summertime. The second study, from atmospheric scientist Mingfang Ting, predicts that warming temperatures are increasing the evaporation of soil moisture and causing summer storms to carry more moisture away from the Midwest (Aronsohn, 2019). Ting’s models predict that precipitation will decrease in the region because of the waning intensity of storms in the region. Storm intensity is affected by temperature differentials between regions. Because of climate change, the polar regions are warming faster, which results in less contrast when compared to the mid-latitude regions. Ting’s models also found that while weaker storms usually move less moisture out of the region, in the Midwest, the storms are moving more moisture out of the region (Aronsohn, 2019). This is because as the air warms and holds more moisture, it triggers a greater moisture difference to build up between the Central Plains and the polar regions. Thus, “the storms are trying harder to remove the moisture from the region” (Aronsohn, 2019). This model predicts that the Corn Belt will experience more hydrological stress, leading to potential decreases in crop yields.

Rye

The second most important grain is rye. Rye is a cereal grass grown extensively as a grain, cover crop, and forage crop. Modern rye is grown extensively in Europe, Asia, and North America where climate and soil are relatively unfavorable for other cereals. Rye thrives in high altitudes and has the greatest winter hardiness of all the small grains, growing as far north as the Arctic Circle (Britannica, n.d.). While rye is grown in North America, it is primarily used as a cover crop. The majority of rye used in American whiskey actually comes from Europe and Canada, with Europe producing approximately 53% of the world’s rye (Minnick, 2018). Former Four Roses master distiller Jim Rutledge believes European rye is better for making whiskey because the flavor is more robust when grown in colder climates. According to Rutledge, selecting rye is a “combination of desired sensory perception, starch content, and enzyme level and the best rye in the last 15 to 18 years has been found in northern European countries” (Minnick, 2018).

Climate change has an observable impact on rye production, which could have a positive influence on rye yields. A study conducted on winter rye in Halle from 1901 to 1980 attempted to examine whether observed climate changes had an impact on crop yields during the 20th century. As shown in Table 2, apart from a few exceptions, “climate fluctuations in years with high yields are connected with positive climate anomalies, and those in years with low yields are connected with negative anomalies" (Chmielewski, 1992). The filled circles represent the high and the low yields, with high yield being defined as crops above the 75%, quantile and low yields being defined as crops below the 25% quantile. A correlation between weather conditions and yield can be drawn, with the difference between the variables being significant. Thus, it is observed that the weather conditions in years with high and low yield are clearly different, which suggest that long-term yield variation in winter rye is related to climatic variations on a greater scale (Chmielewski, 1992). Another study conducted by Chmielewski in 2000, examined the relationship between atmospheric influences and grain yields in relationship to crop density, number of kernels per ear, and kernel weight of winter rye. Through examination of the grain yield and yield components of winter rye in a long-term field experiment at Berlin-Dahlem between 1962-1997, Chmielewski surmised that increased yield of winter rye from 1980s and onwards could be a positive climate change effect (Chmielewski, 2000). There are a few possible explanations for this correlation. While winter rye is more resistant to frost, cold winters with periods of temperatures less than 5°C will induce winter rest in the cereal crop, resulting in reduced activity in plants. In mild winters, winter rest was occasionally interrupted to allow further plant growth, resulting in a large number of tillers (additional stems) being produced (Chmielewski, 2000). Furthermore, warmer temperatures during the phases when tillers and kernels developed resulted in more productive yields overall. Therefore, in contrast to spring cereals such as spring barley and oats, slightly increasing temperatures due to global warming could have a positive impact on the yield level of winter rye, especially higher temperatures during winter (Chmielewski, 2000). Comparing yields observed in the study, warmer temperatures in the last decade of the study (1987-1996) resulted in a 23% increase in yield of winter rye, a 26% increase in yield of crop density, and a 15% increase in kernel number, compared to the cooler first decade of the study (1962-1971) (Chmielewski, 2000). While the positive correlation between warmer temperatures and rye yields is observed, it is difficult to posit causation between the increased yields and climate change. However, the results of the study are promising for the sustainability of grains used in whiskey production.

Barley

Barley is a cereal plant and the fourth largest grain crop globally, after wheat, rice, and corn (Britannica, n.d.). In general, barley is adaptable to a greater range of climates than other cereal crops and is grown all around the world. Barley is primarily used in animal feed, the production of alcoholic beverages, and in food for human consumption. Newly harvested barley cannot be processed into whiskey directly; it needs to go through the malting process to convert the starches in the grain into sugar. The malting process sprouts the barley and produces enzymes that convert the long-chain carbohydrates into simpler sugars that can be processed into alcohol (Knittel, 2019). While barley is more commonly used in Scottish whisky, American whiskey also utilizes barley. Whether it is in small percentages to add a smokiness and earthiness to whiskey or used to make malt whiskey (minimum 51% malted barley in the mash bill), barley use is prevalent in the American whiskey industry.

As examined earlier in relation to beer, climate change may increase the incidence of extreme drought and heat, which could result in a decline in barley yields. The relationship between future increases in global mean (land) surface temperatures and the index of extreme events severity (prevalence and magnitude of concurrent extreme drought and heat during barley-growing seasons and in barley-growing regions) is primarily positive (Xie, 2018). While the prevalence of extreme events severity is approximately 4% as global mean (land) surface temperatures increase up to 3°C, the likelihood increases up to 17-18% with temperature increases of 4-5°C and up to 31% with temperature increases of greater than 5°C (Xie, 2018). Global mean barley yields decrease during extreme events years, with more severe extreme events expected because of rising temperatures. Average yield reduction during these years are projected to be -3% under temperature increases of 3°C, -9% to -10% under temperature increases of 4-5°C, and up to -7% under temperature increases of greater than 5°C (Xie, 2018). Thus, there is a strong relationship between the incidence of severe extreme events and barley yields.

Under multiple crop modelling projections, barley production in the United States actually increases under all climate scenarios despite overall decreases in global yields (Xie, 2018). Economic modelling illustrates that "global- and country-level barley supply declines progressively more in more severe extreme events years," with extreme cases resulting in a mean supply decrease of 27-38% under warming greater than 5°C in Belgium, the Czech Republic, and Germany (Xie, 2018). While the production of barley in the United States may remain constant or even grow, supply may decrease as production losses in barley-importing countries will result in increased demand and upwards price pressure on barley grown in the United States. The United States may increase exports of barley to meet the demand of other countries. For example, Scotland may begin to import more barley to maintain their production of Scottish whisky (scotch), as drier climate during the month of May could decrease local barley production by thousands of tons (Howarth, 2019). While many whisky distilleries in Scotland insist on only using Scottish grains, distilleries may be opening up to the idea of using imported grains in order to maintain their current level of production, or to the development of new varieties of barley that are more resistant to climate change.

Wheat

Wheat is the oldest and most important cereal crop and has its place in a variety of wheat whiskey. To be labelled wheat whiskey in the United States, the mash bill must be composed of at least 51% wheat; other bourbon whiskeys are “wheated,” meaning they use a certain percentage of wheat in their mash bill instead of rye. Wheat is used primarily in food for human consumption and has thousands of different varieties. The two major types of wheat are winter wheat and spring wheat. The type of crop that is cultivated depends on the severity of the winter. The United States is one of the top wheat-producing countries, being surpassed only by China, the European Union, India, and Russia (USDA, 2020).

Climate change will have a drastically negative effect on global wheat production. According to a study conducted by Kansas State, wheat yields will decrease by up to 25% in the coming decades without any adaptive measures put in place (Asseng, 2014). Specifically, wheat production is projected to decline by 6% for each 1°C the temperature rises in the future. A case study on wheat yields in southern Australia from 1990 to 2015 illustrate the climate’s impact on wheat production, where water-limited yield potential (yield of rainfed crops) declined by 27% (Hochman, 2017). A 28% decrease in rainfall accounted for nearly three quarters of the 27% decline in water-limited yield potential; rising temperatures accounting for almost a quarter, and increasing atmospheric carbon dioxide accounting for the final 4% (Hochman, 2017). However, adoption of new technology and management systems have held actual yields fairly consistent, illustrating the benefits and necessity of adaptation in order for yields to combat the effects of climate change.

IV. The Impact of Climate Change on Barrel Aging

According to master distiller Brent Elliott of Four Roses, barrel aging is the most important aspect of the whiskey-making process that is influenced by climate. Aging whiskey in wood barrels is an extremely complex process with a multitude of variables. While research on how warmer temperatures affect barrel aging is nascent, distillers have a qualitative idea of how climate change could have a neutral or positive impact on barrel aging. According to Ian Thomas, distillery director at Virginia Distiller Co., when comparing two whiskies aged in a hot climate versus a cold climate, “you would see more development and exchange of fatty acids, tannins, vanillins, and other maturation components in the warmer climate, leading to a more robust flavor profile” (Waterbury, 2020). Barrel aging is what imparts most of the flavors and color characteristics that make whiskey distinct, and many distillers attribute 40% to 80% of the overall characteristics experienced in whiskies to the interaction between the spirit and the wood barrel (Barecki, 2017). Climate interacts with barreling aging in two main ways: flavor extraction and evaporation.

Temperature drives the rate of reactions that occur in the wooden barrels during aging. In hotter temperatures, the whiskey expands into the pores of the barrel and reacts with the oak, while in colder temperatures, the whiskey contracts back into the barrel with the extracted wood compounds. Inside the barrel, the spirit interacts with two internal structures within the plant’s cell wall, hemicellulose and lignin. Hemicellulose is made up of organic compounds and sugars that are soluble in alcohol, and interaction with heat produces color and caramel notes in whiskey. Lignin is a source of organic compounds that impart vanilla flavors with the help of heat (Barecki, 2017). There are four broad components throughout the wood that further influence the spirit: tannins, lactones/trans-lactones, phenolics, and acids. Tannins affect the mouthfeel of the whiskey, bringing a mouth-drying characteristic. Lactones/trans-lactones, phenolics, and acids bring forth hundreds of different flavor profiles and aromas, such as butterscotch, spices, smokiness, brown sugar, and more, that are often found in whiskey. Whiskey that ages in warmer temperatures tend to mature sooner due to the accelerated interaction between the spirit, the barrel, and the air. According to Dr. Gary Spedding of Brewing & Distilling Analytical Services, “for every 18°F rise in temperature, you double the rate of reactions” (Waterbury, 2020). Thus, the hotter the temperature, the more the whiskey expands into the barrel and reacts to extract compounds out of the wood. While traditional whiskey made in the United States experiences heat cycles of hot and cold temperature, experiments with maintaining hot barrel aging climates show promising results as well. Copperworks Distillery in Seattle maintains their warehouse at a steady 21°C, which accelerates the chemical reactions that are not solely reliant on whiskey-wood interaction (Waterbury, 2020). They claim that keeping barrels warm produces flavors that are traditionally seen with long maturation periods.

Climate also has an impact on the evaporative loss of the spirit aging in the barrel. Humidity levels during the aging process impact the liquid loss and the ABV. Lower humidity levels cause water to evaporate first, which increases the alcohol percentage over time. Higher humidity levels cause alcohol to evaporate quicker than water, which decreases the alcohol percentage over time. The barrel is a semi-permeable membrane that interacts with the environment around it; thus, the higher concentration of water or alcohol flows towards the lower concentration, eventually reaching equilibrium (Waterbury, 2020). Thus, a warm, dry climate will result in more water loss from the barrel, whereas a cold, humid climate will lose more alcohol. Because some compounds are more soluble in water than alcohol, aging in a warming climate could result in less extraction of the compound as warmer temperatures result in higher proof spirits within the barrel. For example, using new oak barrels in a warm climate could result in stronger wood characteristics that overpower the more delicate fruity and floral qualities than would be impacted in cooler, more humid environments (Waterbury, 2020).

Climate change has several implications for barrel aging. In the United States, annual average temperatures have increased by 1°C over the period from 1901 to 2016. Over the next three decades until 2050, annual average temperatures are projected to increase by approximately 1.4°C relative to average temperatures from the recent past (1976-2005) (Wuebbles, 2017). A distillery’s warehouses in Kentucky experience a temperature variation of approximately 4°C from top to bottom. For distilleries that have a multi-tiered warehouse, the difference could extend upwards of 11-17°C. In the interview, the Master Distiller noted that over time, “even a two-degree Fahrenheit difference in the baseline [temperature] will change the quality of the barrels,” and the difference will become more prominent the longer that the whiskey is aged.

V. The Impact of Climate Change on Oak

American white oak, or *Quercus alba*, is the predominant variety of oak that is used to age whiskey. While bourbon requires new charred oak barrels to be used for aging, it does not require white oak specifically. The prominence of white oak is due to its abundance. Climate change affects the terroir of where the oak is grown, which has a subsequent impact on the characteristics of the wood.

Terroir refers to all the factors that contribute to where the oak is grown. Even within the same species, factors such as climate, soil, and topography can contribute to differences in oak that come from different geographical locations. Brown-Forman sources oak from three major terroirs – the Appalachians, the Ozarks, and the northern forests (Emen, 2017). Because of different growing conditions, they see terroir specificities within the oak grown in different locations. For example, these differences can be observed in *Quercus robur* casks that Midleton Dair Ghaelach sources from Ireland rather than Spain. Oak sourced from Ireland shows lower density and higher porosity than oak sourced from Spain because of the terroir, which leads to a more open structure that allows more compounds to be extracted from the oak at a faster rate (Emen, 2017).

VI. The Impact of Climate Change on Water

Climate change is likely to have a significant impact on the water cycle, and in turn, the variability of water access for different regions around the globe. A warmer climate will result in more evaporation from both land and sea and an atmosphere that can retain more water—roughly 4% for every 0.55°C rise in temperature ("Water and Climate Change," 2010). Changes like these are expected to have a negative impact on water accessibility.

Some regions in the United States, such as the Northeast and Midwest, will experience increased precipitation and runoff, especially during the winter and spring ("Water and Climate Change," 2010). Over the past 50 years, the amount of rainfall during heavy precipitation events has increased by 30% during the most intense 1% of storms (EPA, 2017). An increase in precipitation and runoff could result in increased flooding in these regions, contributing to a decrease in water quality and potentially damaging infrastructure that transports and delivers water. Heavy precipitation events could overwhelm sewer systems and water treatment plants in the Northeast and Midwest. Furthermore, heavy rainfall could increase the amount of runoff into river and lakes, bringing sediments, nutrients, pollutants, trash, animal waste, and other materials into water supplies (CCSP, 2008). This could pollute the water supply, making them unusable, unsafe, or require treatment.

In other regions of the United States, such as the Southwest, less precipitation especially during the warmer months, and longer, more severe droughts can result in an increased water demand and shrinking water supply (EPA, 2017). In the Southwest, temperatures have increased by over 1°C in the last century, and drought periods are expected to become more frequent, intense, and longer (EPA, 2017). This region relies on the melting of mountain snow throughout the spring and summer. However, over the last 50 years, there has been less precipitation falling as snow and the snow melt has been occurring earlier. Furthermore, increasing temperatures result in higher evaporation rates, which reduces the volume of water in rivers and reservoirs. These factors will place additional strains on the whiskey industry as distilleries will need to adapt to a change in the availability of freshwater.

VII. Case Studies in Comparable Industries

Examining comparable alcoholic beverage industries and how they are impacted by climate change may provide further insight into how the whiskey industry could be affected. Two relevant industries that would be helpful to examine are the cognac and beer industries.

Cognac

Cognac is a specific type of brandy produced from distilled white wine. The spirit must be distilled twice, using copper pot stills, and aged in French oak barrels for a minimum of two years (Emen, 2015). Furthermore, to be classified as cognac, it can only be produced in one 78,000-hectare area of France using grapes grown from six regions, which are Grand Champagne, Petite Champagne, Borderies, Fins Bois, Bons Bois, and Bois Ordinaires. While cognac can be made from three different varieties of white grapes, Ugni Blanc accounts for 98 percent of all production of the spirit. Cognac's distillation season is usually five months annually from October through March. The distillation process cannot begin until the grapes are harvested and the wine is produced, so most of the distillation process begins in earnest at the beginning of November. The season ends in March because, according to regulation, cognac cannot be made with wine which has added sulfites. Sulfites are necessary to preserve the wine. March signifies the end of the winter season and rising temperatures, which could compromise the quality of the wine waiting to be distilled. Then, the distilled product (called eau-de-vie) is aged in French oak barrels, and finally must be blended to be considered cognac. Some of the best-known brands are Hennessey, Martel, Courvoisier and Remy Martin.

Climate change has forced the cognac industry to depart from tradition and begin searching for alternatives to adapt, such as testing new grape varieties and employing new weather resistant technology. Cellar Master of Rémy Martin, Bapiste Loiseau, shared that climate change is the single largest challenge his team sees in cognac production (Witte, 2020). The three main problems that the cognac industry is facing are rising summer temperatures, increasing extreme weather events, and warmer winters.

Rising summer temperatures affect the quality of cognac. Good cognac is made from acidic wine. However, Ugni blanc grapes have been ripening quicker and losing acidity as a result of warmer and drier summers in the cognac-producing regions (Hopkins, 2020). The balance between sugar and acidity is important because sulfite is not added to cognac as a preservative. Therefore, acid is pivotal in wine preservation as it awaits distillation. As a result, winegrowers have shifted harvest dates earlier between 10-30 days; cognac grapes are removed from their vine in September rather than October to maintain the correct levels of acidity and sugar. However, harvesting early poses a problem because the grapes have fewer aromatic components that are important flavor characteristics in the spirit. To further adapt to the warming summer temperatures, cognac houses and winegrowers are testing different grape varieties to see which are resilient to global warming, hardy to disease, resistant to rot and mildew, and which have higher acidity contents (Kiely, 2019). Martell has partnered with the French National Institute for Agricultural Research (INRA) to create new cultivars through natural breeding and have been able to experiment with small new vines which are resistant to disease and are slower growing (Hopkins, 2020). Another idea, inspired by winegrowers in Japan, is to mitigate the warmer summer temperatures by creating "paper hats to sit on top of the bunch of grapes with cool air blowers to help reduce the heat" (Kiely, 2019). Overall, the actions taken are preparing the industry to be agile as the changing climate has forced them to adapt for long-term action.

Increasing extreme weather events also put the cognac industry at risk. In the three years between 2016-2018, the cognac industry has been crippled by extreme and unpredictable weather. In 2016, severe storms that brought hail, heavy wind, and rain affected up to 6,000 hectares of vineyards (Kiely, 2019). These events led to a loss of harvest and significantly lower yields for several producers. In 2017, extreme cold also affected yields. A spring frost settled on the Cognac region, which destroyed a substantial share of the year's harvest; over 25% of the Cognac area was affected by the spring frost (Kiely, 2019). In 2018, a wave of hailstorms tore through the region in May, causing serious damage to over 3,500 hectares and affecting over 10,000 hectares of cognac grape-growing regions. The most afflicted 3,500 hectares lost an estimated 80 percent of the vines because of the hail (Kiely, 2019). These weather events have increased the awareness of climate change and forced the industry to adapt. To combat these events, several measures are being considered to prepare the region for future adverse weather conditions. Catherine le Page, director of the trade body of the Bureau National Interprofessionnel du Cognac (BNIC), expressed that experiments have been conducted since

2019 at 10 properties to prepare the Cognac region (Kiely, 2019). For example, anti-hail netting could be installed for vineyards to reduce the risk of severe hailstorms. Cognac producers have also taken inspiration from other wine-producing regions to fight frost, such as using propellers and wind machines found in California to mitigate the risks of cold weather events brought about by climate change.

Finally, warmer winters also bring problems that the cognac industry must reckon with. When temperatures do not drop during the winter, insects, bugs, and diseases become a bigger threat because more bugs survive (Jacki, 2018). Furthermore, if the seasonal temperatures rise earlier on, then the grape vines are at risk of budding sooner and being damaged by frost and hail. Experimentation with different pest and temperature resistant varieties could be fruitful, however short-term solutions such as an increased use of pesticides may not be a long-term solution.

The process of creating cognac shares a lot of similarities with the process of making American whiskey. Both cognac and whiskey take raw materials (grapes and grains), and process them into a preliminary input (wine and beer). Then, these inputs are fermented and distilled to extract the alcohol, and ultimately put into wood barrels for aging. However, the cognac industry and the American whiskey industry also have their differences. A huge part of the challenge that the cognac industry is facing regarding climate change is because the grapes can only come from a limited geographical region. Thus, while other whiskey or brandy distillers can consider growing new vines in different regions, cognac must be produced within the 78,000-hectare area of France. This puts increased pressure on the industry to adapt in order to survive, while other industries can plant or source their grains from other geographical locations.

Beer

Beer is an alcoholic beverage produced by combining water, malt, hops, and yeast through a boiling and fermenting process. The category of beer is extremely broad and brewed all around the world, but all beer falls into two categories: ales and lagers. The difference between the two is the yeast used during fermentation, timing, and temperature. In ales, *saccharomyces cerevisiae* gathers at the top of the tank during fermentation while in lagers, *saccharomyces pastorianus* gathers at the bottom (Holl, 2020). Ales age for a few weeks at a temperature of 22-30°C, while lagers can age for months between 18-25°C. These differences result in a taste that is often aromatic and fruity for ales, and crisp, clean, and refreshing for lagers (Holl, 2020). Different styles of ales and lagers are the result of experimentation with different inputs to the process, such as using different hops, grains, barley, and other ingredients.

The brewing process to make beer consists of malting, milling, mashing, extract separation, hop addition and boiling, removal of hops and precipitates, cooling and aeration, fermentation, separation of yeast from young beer, aging, maturing, and packaging (Young, n.d.). To summarize the process, we can consolidate the process into five main steps: malting, mashing, boiling, fermenting, and bottling and aging. First, the grains are harvested and put through a process of heating, drying out, and cracking to isolate the enzymes pivotal for brewing. Then, the grains are steeped in hot water to activate the enzymes and release the sugars. After about an hour, the liquid is drained from the solids and the sticky, sweet liquid remaining is called wort. Then, additional ingredients, such as hops and spices, are added as the wort is being boiled. After the wort is done boiling and cooling, it is put into a fermentation container where yeast is added. The beer is stored while the yeast consumes the sugars and produces alcohol. After this process is complete, the beer is ready to be carbonated, whether naturally from the yeast or artificially, and bottled to be consumed.

While the world of beer has developed and evolved over centuries, climate change is a pressing issue that is currently affecting the industry. While beer can be made with a variety of ingredients, the predominant inputs to the process are malted barley, hops, and water. Thus, the three main problems the beer industry is facing are how climate change is affecting barley yields, hops, and freshwater.

According to a study conducted by a team of researchers in China, the U.K. and the U.S., climate change could have a significant impact on the world's supply of barley. Projecting that the frequency and severity of drought and heat extremes will increase in the upcoming decades, these climate events may cause the world's supply of barley to decrease by 3% to 17% depending on the severity of the conditions (Xie, 2018). The greatest decline in yields would occur in tropical areas such as South America and Central Africa, whereas yields in the United States are projected to rise. However, these increases are not enough to offset the global decline in production. Decreases in the barley yields worldwide could result in proportionally larger decreases in the amount of barley used to make beer, decreases in beer consumption, and increases in beer prices. Under the most severe climate events, global beer consumption could decline by 16% and beer prices would double, on average (Xie, 2018). Even under less severe climate events, global beer consumption could drop by 4% and beer prices would increase by 15%.

While yields are predicted to rise in the Northern regions of the United States, the United States faces a different climate-related concern. According to the American Barley Malting Association, climate conditions have affected the growing process for barley within the United States. In 2019, rainy conditions in the Midwest delayed planting and harvesting in some areas and even caused a condition called pre-harvest sprouting in some cases (Forgrieve, 2020). Pre-harvest sprouting, or the premature germination of grain before harvest, can cause barley to be unsuitable for use in beer. Shifting climate conditions in the United States have already affected where barley is grown; while North Dakota used to be the top producer of barley in the United States, Idaho has come out on top as conditions in North Dakota have gotten wetter (Forgrieve, 2020).

However, beer industry leaders were not as alarmed by the study. The Brewers Association, an American trade group of over 5,400 brewers, called the study “largely an academic exercise and not one that brewers or beer lovers should lose any sleep over” (Chappell, 2018). Furthermore, the Brewers Association economist Bart Watson stated that the beer industry “certainly understands and is already preparing for shifts in climate,” indicating the industry’s grasp of climate change and pertinent adaptation methods. The first method consists of utilizing lab-grown enzymes as a substitute for malted barley. A study conducted by DuPont Nutrition and Biosciences compared the results of producing beer using 100% malted barley and producing beer using several lab-grown enzymes. By using these lab-grown enzymes instead of relying on the naturally occurring enzymes in malted barley, brewers have more flexibility in what ingredients are used to make beer. The results of the study show that using the enzyme instead of malting the barley can reduce energy use by 57%, lower CO2 emissions by 32%, use 29% less water, and require 10% less land (Scott, 2020). Utilization of enzymes may allow brewers to reduce usage of barley and to switch to more climate-resistant grain varieties.

Changes in climate have also impacted the cultivation of hops, which are the flower buds that impart bitterness, unique flavors, and aromas to the beer. Changing climate and weather patterns have shifted where hops are produced. New York used to be the primary hop-growing area in the United States, but the Pacific Northwest has become the dominant hop-growing area because the long hours of daylight during the growing season is more favorable (Forgrieve, 2020). Now, 73% of the hops grown in the United States are from the state of Washington, with the rest roughly split between Oregon and Idaho (Kennedy, 2016). Furthermore, increasing temperatures and drought are threatening hop production. In 2015, the state of Washington saw moderate to severe drought conditions in the latter half of the year. The extended heat and drought had a negative impact on the yields of some aroma varieties, such as Willamette and Centennial, that are less heat resistant varieties (Kennedy, 2016). However, most of the flavorful hop varieties grown in the Yakima Basin of Washington have been specifically developed for the hotter Yakima climate, compared to the less heat-tolerant European-style aroma hops. Growers in the region were also able to adapt to the drought by utilizing groundwater supplies/other sources, or idling a portion of their less valuable land to focus water supplies on higher value crops (Kennedy, 2016).

Finally, climate change is impacting the availability of freshwater. Making beer is a water-intensive process; while beer is typically 90% - 95% water, most of the water used in beer production goes towards farming. Furthermore, the brewing process requires 5-6 gallons of water to produce one gallon of beer inside the average craft brewery, which goes toward cleaning, cooling, and packaging (“Why Climate Change,” 2020). In California, prolonged periods of drought have reduced the natural water supply. Typically, craft breweries in Northern California draw water from the Russian River. However, dry conditions have led to a reduction in the amount of water released from the Lake Mendocino reservoir into the Russian River, which results in an increased reliance on groundwater for beer production. While this adaptation method allows the breweries to continue operations, there are some potential side-effects. Groundwater is rich in minerals, which may not synergize well in beer. Jeremy Marshall, head brewer of Lagunitas, likens it to brewing beer with Alka-Seltzer (Bland, 2014). Some wells may have high concentrations of nitrate, iron, and manganese, which could provide undesirable flavors for beer. Lagunitas considered shifting their operations entirely to their Chicago facility to combat the water scarcity or installing a reverse-osmosis system to treat the groundwater. However, these methods will not improve freshwater availability. In the case of reverse-osmosis filtering, it will actually be more water intensive because only 70% of the treated water is usable (Bland, 2014). Thus, conservation may be the most effective method to sustainably use water. Minimizing the amount of water used during farming, such as by using drip irrigation, is one example. Another example is to conserve as much water during operations as possible, such as by installing hot-water recovery systems. These examples illustrate the industry consensus that conservation is the most effective way to save water.

PART III: INTERVIEWS AND QUALITATIVE ANALYSIS

VIII. Purpose of the Study

The purpose of the study was to determine how climate change will affect different steps of the whiskey-making process and investigate potential adaptation methods that distilleries could employ. I examined whiskey distillers' perception of climate change's impact, experience with climate variability, differences based on geographic region, and methods of adaptation to climate fluctuations. Through the interviews conducted, I gathered information into the perceived impact of climate change and any potential threats to the industry. With this information, I compiled adaptation methods for whiskey distilleries that would inform them about the potential consequences of climate change and could aid in future endeavors to adapt.

IX. Methodology

Research Methods

The research question I sought to address was “How have the effects of climate change impacted the American whiskey industry, and what can be done to adapt?” To explore the relationship between climate change and the whiskey industry, I relied on primary and secondary data. I conducted interviews with distillers at five different distilleries in Texas and Kentucky to gather data on both the quantitative and qualitative effects of climate change that they have observed. Comparing distilleries in Texas and Kentucky allowed me to gather quantitative data on the climate differences between the two regions. I also utilized secondary data by reviewing studies on climate change to observe its impact on crop yield, temperature fluctuations, precipitation fluctuations, and more. My method of data collection consisted of research and interviews. This information helped inform my methodology for conducting interviews.

Participants

Whiskey distillers from five distilleries across Texas and Kentucky participated in the current study. Whiskey distilleries were chosen based on the criteria that they sourced their own grains to use in their mash bill, produced distillate that they aged, and sold product for consumption. The criteria for selecting interviewees were that they had to be an employee of the distillery, have experience with the whiskey-distilling process, understand the process at the distillery they worked at, and were knowledgeable on how climate impacts their process. The official titles of the participants interviewed were Distillery Manager, Head Distiller/Head Blender, Co-Founder and CEO, Master Distiller, and Co-Owner and Chief Scientific Officer. All participants had been in their profession for at least five years and had a deep understanding of their respective distilleries.

Procedures

In order to gain better insight into how whiskey distillers have experienced climate change, I reached out to 20 distilleries distributed between Texas, Kentucky, Colorado, and Utah in late November to request participation in the study and a follow-on interview. Each distillery was reached out to by using an email provided on their website or by using their website's "Contact Us'' page. I asked to speak to the head distiller or someone with distilling experience. The email explained that the format of the interviews was semi-structured and qualitative to learn about their distilling process, gain insight into how climate affects their process, and the broader implications of climate change on the whiskey industry. If the distiller agreed to an interview, the interviewer let the distillers know that they would be contacted in early January 2021 to schedule an interview. Each interview was confirmed and conducted during late January. The study received seven responses and five interviews, resulting in a 35% response rate and a 25% interview rate. The email explained that the interviews would take place in-person or through phone/zoom, depending on their comfort, and would last approximately 30 minutes to an hour. Due to the pandemic, all interviews were conducted online. The remaining distilleries did not respond or redirected me to their website.

The topics addressed in the interview touched upon the distiller's perception of climate's effects on the whiskey-making process, experience with temperature variability, and perceived impact of a future increase in climate change. Additional questions gathered information regarding the distiller's experience, potential adaptation methods to climate-related effects, and the distillery's current environmental stewardship efforts. The interviewer also asked follow-up questions based on topics the interviewee brought up. Each interview was typed after obtaining verbal consent from the interviewee.

Measures

The interviews followed a semi-structured format, with a few set questions to establish comparability across different distilleries, while asking unique follow-up questions on topics brought up by the distillers. The interviews were transcribed and thematic analysis was conducted. This involved coding all the data before identifying and reviewing five main themes. Each theme was examined to gain further insight into the distiller's perception of climate change and its impact.

The first standard question regarding climate change asked how climate interplays with the whiskey-making process. I followed up with a question about how climate change would potentially influence their process. The purpose of these questions was to understand to what degree the distilleries were cognizant of the effects of climate on their processes and how these processes would be adapted if climate were to change. Then, I discerned the distiller's perception of how impactful climate change would be on the industry. These perceptions may have played a role in informing what adaptation methods, if any, the distillery was implementing or thinking of implementing. The last question was an open-ended inquiry to see if the distiller had ideas on how to be proactive if temperatures were to rise. The questions were asked with the intent to gather information from the interviewees but were also left open-ended to give room for follow-up. This method allowed the distillers to answer the questions asked while also allowing them to emphasize their thought processes in order to better understand what they prioritized.

Analysis

To analyze the interview responses, thematic analysis was conducted to extract themes for evaluation. Thematic analysis consisted of five steps: familiarizing yourself with the data, generating initial codes, searching for themes, reviewing themes, and defining names and themes (Braun, 2006). Before the interviews began, the interviewer reviewed steps in the whiskey-making process to guide analysis and inform potential codes. To become familiar with the data, the interviewer transcribed each interview. Then the interviewer reviewed the data through repeated reading. To generate initial codes, the interviewer highlighted key words or phrases in the transcript which were transferred onto a consolidated Excel sheet. The list of 60 key words and phrases came from all five interviews. To search for themes, the interviewer reviewed the list of words and phrases and grouped them based on related words, such as “water,” “footprint,” or “grain variety.” There were 11 initial themes based on the relationship between codes. To review the themes, the 11 initial themes were grouped together based on the overlap between themes; for example, “adaptation” and “reducing carbon footprint” had similarities that resulted in combining the two. Frequency counts were used to determine which of the resulting themes were most prevalent across the five interviews. A cutoff frequency of five was chosen to focus on themes that were more prevalent. The codes with less prevalence were still examined for importance and provided insight to other themes. Codes that did not meet the cutoff frequency were usually unrelated to the whiskey-making process, with “fermentation” being the exception. Related codes were typically descriptors of the process, with minimal focus on how climate change impacts the fermentation process. The resulting themes were analyzed and used to guide further research and literature review to examine the effects of climate change on the whiskey industry. After the data was analyzed and research was conducted, a copy of the consolidated research was sent to each interviewer.

Research on climate change is extensive, but literature on its effects on the whiskey-making process and industry is limited. Conducting semi-structured interviews is beneficial to investigate trends and themes that distillers experience first-hand, but usually produce results that cannot be generalized beyond the sample group. The distilleries I interviewed were in Texas and Kentucky, but distilleries in colder climates may have different experiences with climate change. However, interviews provide topics for investigation that the current literature may not address.

PART IV: RESULTS

X. Results

Thematic analysis of the qualitative data gave rise to six major themes described below: grain variety, barrel aging, wood, water, temperature variability, and adaptation methods. These themes include an analysis of the data and adaption recommendations.

Grain Variety

The theme of grain variety emerged out of the codes “grain varieties,” “biodiversity,” “grain quality,” and “local taste from local grain.” Grain variety refers to the distinct characteristics of different varieties of the primary grains used in whiskey.

Three of the five distilleries explicitly focused on grain variety in the whiskey-making process. One distillery has an emphasis on biodiversity and their vision is to work “100% with local farmers to cut down on transportation footprint and create a product that has a local taste from local grain and grain variety.” They use locally grown white corn and elbon rye in their product and are working with Texas A&M to increase biodiversity in their region through growing different grain varieties. Another distillery sources all their grains from a single farm in Texas and emphasized the impact climate change has on raw material yields. This distillery saw difficulty in last year’s precipitation patterns that impacted corn yields; an increase in rain during the planting process disrupts the timing and creates barriers that reduce yield. Beyond cultivating grain varieties to maximize yield, they are experimenting with varieties of corn with different flavor profiles that are more resilient in varying climate conditions. The third distillery also builds relationships with local farmers to maintain consistency in grain quality and variety. Their corn, rye, wheat, and malted barley are sourced from Kentucky. This distillery stated that grain quality is dependent on climate. In the presence of significant weather events, grain quality can be negatively impacted, which might require new varieties that are heat and/or moisture resistant if current varieties have problems.

In contrast, a distillery claimed that climate change does not have a big impact on grain variety because most American whiskey uses primarily yellow dent corn, which is a GMO product resistant to pests. However, grain variety and diversity are prevailing themes among distilleries which are concerned about climate change. While yellow dent corn may be resistant to pests, increasing grain variety could have positive effects, such as adaptation to changing precipitation patterns, water access, and consumer preferences.

Barrel Aging

The theme of barrel aging emerged out of the codes “barrel aging,” “extract profile,” “characteristics of the whiskey coming out of the barrel,” “angel’s share,” “climate controlling in warehouses,” “chemical reactions driven by temperature,” and “tannins from oak barrels.” The theme of barrel aging refers to the process by which whiskey enters seasoned American oak barrels and is placed in warehouses to age.

“Angel’s share” was a prevalent code present in this theme. “Angel’s share” refers to the amount of volume lost in the barrel on a per year or aggregate basis. The angel’s share is dependent on a variety of factors, including temperature and humidity. Temperature variability from hot to cold and vice versa is what expands and contracts the liquids within the barrels, which draws out flavor characteristics from the wood. Humidity levels also affect the amount of evaporative loss a barrel experiences; dryer climates will have higher evaporative loss because the water molecules are smaller than alcohol molecules, which allows water to escape easier. Both temperature and humidity affect the aging loss and determine what share is taken by the angels.

Four distilleries mentioned barrel aging being affected by climate, with two distilleries asserting that barrel aging is affected the most by climate of any part of the whiskey-making process. A distillery believes that everything in the warehouse is dependent on weather and temperature, which makes Kentucky perfect for aging whiskey. Temperature fluctuations, along with humidity levels, result in whiskey extracting flavor, color, and characteristics in the barrel. Many of the chemical reactions that take place within the barrels during aging are driven by temperature. This distillery predicts that even a two-degree difference in the baseline temperature will change the quality of the barrels of whiskey, which can lead to different characteristics of the whiskey coming out of the barrel and getting a different extract profile. A second distillery also states that barrel aging is the field where climate effects are most applicable. According to the second distillery, “Kentucky sees a loss of 4-5% per year, Scotland sees a loss of 2-3% per year, and Texas sees a loss of 9-10% per year.” Aging loss is the most concrete and measurable statistic and is harsher in Texas because of the larger temperature swings and climate tendencies. Regarding climate change, this distillery assumes that future changes in temperature could result in changing whiskey characteristics, such as less tannin content extracted from the oak barrels, if winters are less cold.

The third distillery provides further insight into barrel aging in different regions of climate variability. Over the course of four years, they see a 74% yield on average, which means they lose 26% over the course of four years, and up to 29% in the mid-tier floors of the warehouse. This distillery notes that bourbon and American whiskey producers generally do not climate control their warehouses, so their yield loss is higher compared to other industries, like scotch, that partially climate controls by putting their warehouses underground. The fourth distillery, located in Kentucky, notes how Kentucky has a climate with high moisture and humidity, which reduces yield loss due to evaporation. They brought up that some distilleries in Nevada cycle warehouses with moisture in order to reduce evaporative loss. This distillery also explained how climate change can result in more adverse weather events in the future. These weather events could cause an increased risk of losing warehouses to lightning or tornados.

Another prevalent code that addressed potential adaptations to climate-related barrel aging was “climate controlling warehouses.” Climate control refers to a heating and cooling system within the warehouse that controls temperature and other climate related variables. A change in the baseline climate could result in a change to the quality of the barrels, which can be mitigated by climate controlling warehouses. A distillery noted that some distilleries already implement climate-controlled warehouses to mimic climate conditions in Kentucky. However, climate controlling warehouses is resource intensive.

While climate change can bring variability in temperature and humidity, these changes may not have as large of an impact as expected. One distillery in Kentucky has single-story warehouses that stack six barrels high. There is a temperature variation of 4°C from the top of the warehouse to the bottom. The more tiers in a warehouse, the larger the temperature delta will be. Because barrels in warehouses already experience natural climate variations based on their tier, there may not be as big of a difference in the short term in regard to barrel aging. However, the variation still affects the characteristics of the whiskey; while the same product goes into the barrels, it might come out different based on where it is stored in the warehouse. A baseline change in climate, and the longer the whiskey ages in the barrel, will change the quality of the barrels.

Wood

The theme of wood emerged from the codes “source wood from different areas,” “oak trees,” “wood is seasoned by climate,” “use new types of wood,” and “sustainable forest management.” The theme of wood refers primarily to the American white oak that is used to make barrels for aging whiskey and can also include other alternative wood used for aging. The discussion centers primarily around American white oak because it is legally required to be used for whiskey to be considered bourbon.

Three distilleries examined the effects of climate change on the wood they use in the whiskey-making process. One prevalent code that addresses climate's impact on the quality of the wood used to make the barrel is "wood is seasoned by climate." One distillery states that wood is seasoned to make the barrels, and climate is influential to the seasoning process. The seasoning process refers to drying out the wood to prepare it to be made into whiskey barrels. How the wood is dried and for how long has a direct impact on the quality of the whiskey (Sloan, 2014). Leaving new, unseasoned wood outside to season not only dries out the wood, but also gives the wood "exposure to enzymes and fungi that break down wood chemicals into smaller ones that are easily extractable." Furthermore, it increases porosity and extracts glucose and polysaccharides from the wood that detract from the taste. Because wood can be left outside to season for over a year, climate is an essential component of this process.

Discussion on potential future adaptations for wood was extensive; these adaptations include sourcing wood from different areas, diversifying the types of oak used in barrels, and sustainable forest management. Climate change may bring pressures that force distilleries to adapt. Another distillery discussed how climate change could increase disease pressure, plant pathogens, nematodes, and fungi, which could negatively impact the white oak population.

A third distillery discussed how climate impacts the quality of wood in different regions. This distillery currently sources their wood from Kentucky and Missouri but is looking into potentially sourcing wood from different areas in the United States. They believe that climate affects the oak trees that are used and factors into cask management for distilleries. Cask management refers to the process of selecting wood to be used for barrels that age the whiskey. For example, this distillery brought up that too much rain, or too little, would affect the quality of the wood. Because a large part of the whiskey characteristics is imparted from the wood in the barrels, cask management is important to guarantee the quality of the product.

Finally, climate change affects the wood molecules that are extracted into the whiskey. A fourth distillery stated that if climate change were to increase overall temperatures, they could potentially utilize American, French, and Hungarian oak for their barrels. Higher temperatures could extract some wood characteristics in undesirable quantities, so climate change could result in a change in whiskey characteristics that are influenced by the wood being used.

Water

The theme of water emerged from the codes “fluctuation in precipitation,” “access to water,” “rainy seasons impact corn yields,” “precipitation change affects yields,” “rivers drying up,” “increase in rain during growing season,” “sustainability of water,” “conserves water,” “mitigate water usage,” and “reuse water.” The theme of water primarily centers around water conservation and methods to reuse water more efficiently.

Four distilleries discussed the importance of finding methods to conserve water as a response to climate change. The first distillery illustrated how important water is to the whiskey-making process noting that while water composes a significant portion of the volume in whiskey, it is also crucial in generating steam during the heating process. For this distillery, sustainability of water is a process that they are prioritizing. Making whiskey is a very water intensive process; each batch of whiskey is 16,000 gallons, where 14,000 gallons is water and 2,000 is the rest of the whiskey ingredients. Furthermore, the whiskey still, which is used during the distillation process, is powered by steam. Heating up the beer takes 2,150 gallons of water per batch, and once the inputs are passed along to the whiskey still, another 9,000 gallons of water is used as steam. This distillery sources their water from the city, but the water goes through a lot of water filtration and Ultraviolet (UV) processing. Reverse Osmosis (RO) filtration is very wasteful because 50% of the water is lost during the process. Thus, this distillery tries to conserve water by developing on-site wells to get their own water and reduce RO water usage. Furthermore, they are looking into reusing steam as a method of conserving water.

The second distillery also recognized that their process was heavily impacted by water and climate. Originally, this distillery sourced their water from the Salt River, so they were at the complete mercy of the flow rate of water going through the river at any time. First, they would pull water from the river and divide the water into three strings. One string goes into the actual product and is put into the fermenter. Another string is used to make steam, and the final string is used as cooling water. The cooling water is necessary because every time the inputs are heated up, it needs to be cooled rapidly afterwards. After the cooling water is put into contact with the product, it increases in temperature and is sent to a pond to cool. After the temperature of the water drops enough, the water is put back into the river. Occasionally during the summer, this distillery would have to shut down because the river would start to run so low that you could not pull water from it. Due to fluctuations in rainfall and drought patterns, using water from the river could be unreliable. To mitigate the risks that climate change brings to their water access, this distillery invested in a closed water loop system and a chill plant in a new expansion that doubled the size of their distillery and reduced their water usage. As a result, this distillery does not have to rely on the Salt River for their water needs.

The third distillery recognized that precipitation and access to water may be vulnerable to climate change. This distillery believes that the main environmental concern related to climate change is not the additional heat that comes from climate change, but the fluctuation in precipitation as well as access to water for farmers. The farmers of the grain-growing region in the High Plains of America rely on the Ogallala Aquifer, which supports one-sixth of the world's grain produce (Frankel, 2018). The recharge rate of the aquifer is much slower than the usage rate, which could pose a threat to water access in the future for grain growers. This distillery believes that a potential adaptation method is to utilize drip irrigation as opposed to spray irrigation as a way of conserving water. Drip irrigation conserves water by maximizing the efficiency of water intake by the grains, while reducing wasted water. Their farmers use more advanced technology, such as probes, to measure moisture.

The final distillery discusses how they recycle their distillery stillage as a method of conserving water. Distillery stillage is the resulting wastewater at the bottom of the still during the distillation process after the alcohol is separated at the top. In general, distillery stillage and water for the system cooling are the main contributors in total volume of wastewater produced during steps of the alcohol production (Mikucka, 2020). Stillage can be up to 12 times the volume of the alcohol produced, and this distillery generates over 100,000 gallons of distillery stillage every day. Distillery stillage could pose an environmental concern because it pollutes the water in several ways. First, the dark color of the stillage can block out sunlight, reducing the oxygen content of the water and harming aquatic life. Second, it can cause eutrophication of bodies of water because of its nutrient-rich content. Many distilleries discard their stillage down the drain and pay enormous fees to do so. However, this distillery gives their stillage to local cattle farmers to recycle the nutrients and water.

Adaptation

The theme of adaptation emerged from the codes “have to adapt,” “improved ventilation,” “infusion mashing process saves energy,” “energy through wind, farm, and solar,” “waste footprint is small,” “minimize transportation footprint,” and “reduce waste.” The theme of adaptation primarily refers to methods distilleries can employ to adapt to climate-related variables. Whiskey distilleries naturally think in the long term due to the extended timeframe of their production and aging processes. While variations in climate may not be extreme year to year, over time, the effects may compound. Thus, it is important for distilleries to have adaptation methods in mind. Climate change may force distilleries to adapt in the future, both directly and indirectly. Two factors that could have a drastic impact on the whiskey industry are governmental regulation and shifting consumer preferences.

The pressure of governmental regulation and consumer preferences can be observed in the Scottish whiskey industry. In 2019, the Scottish Government passed the Climate Change Bill which set targets to reduce Scotland’s emissions of all greenhouse gases to net-zero by 2045 at the latest (“Climate change”, 2019). These targets include interim reduction targets of at least 56% by 2020, 75% by 2030, and 90% by 2040. This Bill amends Scotland’s Climate Change Act 2009, which created the statutory framework for reducing greenhouse gas emissions in Scotland. As a result, distilleries in Scotland have been forced to adapt to comply with government regulations. Currently, there is no overall policy approach to reducing emissions in the United States. While the United States Environmental Protection Agency (USEPA) has the authority to regulate greenhouse gas emissions in accordance with the Clean Air Act (CAA), most regulations that the USEPA sought to implement were struck down by the Supreme Court during the Obama Administration (ICLG, 2021). It is uncertain whether Congress will amend the Clean Air Act or pass a climate change bill; nevertheless, it would be prudent for distilleries to be cognizant of potential climate change regulations that the government could enact, with an example provided by Scotland.

Scotland's Climate Change Bill also illustrates how shifting consumer preferences towards more sustainable distilleries could impact the whiskey industry. How environmentally conscious a distillery is could become a part of its brand image. Diageo, the world-leading whisky producer responsible for 24 Scottish whiskey brands, faced scrutiny from several environmentalists for failing to reach their reduction targets. In 2008, Diageo set eight targets to improve its environmental sustainability by 2015 but was only able to meet one of them. The company's failures were seen as "extremely disappointing," "particularly concerning," and "supremely ironic" by different environmentalists ("Diageo drinks giant," 2015). However, Diageo still made investments and progress in reducing its carbon footprint, channeling over $140 million in renewable energy projects at distilleries in Scotland. While Diageo was facing scrutiny in Scotland, they also received praise for their operations in the United States. From 2008 to 2015, Diageo's North American division was able to cut emissions by over 80% and was described as a "stunning carbon achievement" (Winston, 2014).

Climate change is a growing issue among younger Americans, with 70% of adults under age 35 worried about global warming compared to the 56% of adults 55 and older that are worried (Reinhart, 2018). There are several factors that could explain the different views towards climate change across generations. First, older Americans may not believe that global warming will pose a serious threat in their lifetime, with less time for the effects of global warming to be actualized. Second, younger Americans could be more exposed to climate change as a topic in their formative years, while older Americans may not have had as much exposure until recently. According to data from Drizly, the most significant portion of bourbon consumers tend to be males within the age range of 28 to 39 years old, with the average age over the 2018-2020 period being 37.84 (Bevalc Insights, 2020). As the average customer is weighted increasingly towards being a millennial, consumers may be more aware of the impact of climate change and have positive reaction towards distilleries that prioritize environmental stewardship.

Adaptation recommendations in this section are gleaned from a combination of findings from the literature review and qualitative analysis of the interviews. The findings in this section revolve around utilizing more sustainable grain varieties, climate controlling warehouses during aging, utilizing new types of wood in barrels, increasing water efficiency and sustainability, and adopting methods to reduce carbon footprint.

Recommendation 1: Consider using more sustainable grain varieties

Distilleries should consider using more sustainable grain varieties when making whiskey. Based on information gathered from literature review regarding climate change's impact on crop yields, corn, barley, and wheat could be negatively impacted while rye could be positively impacted. Some of the distilleries interviewed are already experimenting with different grain varieties to improve sustainability, experiment with flavor profiles, and increase biodiversity. To adapt, distilleries can replace traditional corn, barley, and wheat grain varieties with more climate-resistant varieties and/or increase the amount of rye in their whiskey.

Corn is a staple ingredient in American whiskey, and fortunately, newly available drought-tolerant (DT) corn became broadly available in corn varieties between 2011 and 2013. By 2016, 22% of the total corn acreage in the United States was planted with DT corn varieties (McFadden, 2019). Similar adaptations can be made for barley and wheat used in American whiskey production. While changing varieties of corn may have an impact on flavor, switching to more climate-tolerant corn varieties could stabilize the grain supply chain for distilleries.

Distilleries also have an opportunity to diversify their product mix by investing more into rye whiskey. Rye yields are projected to increase with global warming, which may make rye cheaper and more available as a raw input. Although rye whiskey is not as popular as bourbon, with sales of $236 million compared to bourbon sales of $1.78 billion in 2019, rye whiskey has enjoyed a resurgence of popularity (Roberts, 2020). Since 2009, volumes of rye whiskey have increased 1,275%, up to 1.2 billion cases in 2018 ("Rye Whiskey," 2020). Four Roses, a distillery in Kentucky, employs only two mash bills for all of their products; the first consists of 75% corn, 20% rye, and 5% malted barley, and the second consists of 60% corn, 35% rye, and 5% malted barley ("Our Process," n.d.). Distilleries could expand their product mix to include rye whiskey with up to 95% rye in the mash bill.

Recommendation 2: Climate control warehouses

As discussed earlier, barrel aging in warehouses plays a pivotal role in imparting flavor and color into whiskey. Climate change could bring increased baseline temperatures and increased temperature volatility, which threatens distilleries' ability to maintain the quality of their product. To mitigate this risk, warehouses can be climate controlled to maintain climate consistency during the aging process.

While the science surrounding the climate's interacting with barrel aging are not exact, distilleries understand the important role that climate plays during the aging process. An ongoing study conducted by Buffalo Trace distillery seeks to examine the impact of climate on whiskey aging through an experimental warehouse opened in 2013. This experimental warehouse "X" analyzed how temperatures affect the aging process of whiskey and collected 9.1 million data points (Hopkins, 2019). While the study has not concluded, this experiment illustrates how being able to control the environment that whiskey ages in could bolster quality and consistency in the final product.

Recommendation 3: Utilize new types of wood during aging

Currently, American white oak is the most popular oak used for barrel aging because it fulfills legal requirements and is the most abundant oak. However, distilleries can use different types of oak to mitigate disease pressures in the oak and control the concentration of wood compounds that the whiskey absorbs.

Utilizing different types of wood could mitigate the increased disease pressure, plant pathogens, nematodes, and fungi that climate change may bring. For example, chestnut and elm trees have diseases that kill the host tree; these diseases are referred to as chestnut blight and Dutch elm disease, respectively. Climate change could increase the risk for a new oak pathogen that hinders the progression of the industry. A distillery brought up that currently there is a plant pathogen called *Phytophthora ramorum* that is the cause of a forest disease called "Sudden Oak Death" that has killed millions of tanoak trees and several other oak species ("What is Sudden Oak Death," 2021). Thus, finding alternative types of wood to use for whiskey aging may not be just a luxury in the future, but a necessity.

Utilizing different types of wood to age whiskey can also counteract the effects that warmer temperatures have on the wood-whiskey interaction. If temperatures increase, then the whiskey would not have as much tannin from the oak because cold temperatures cause the wood to contract and draw out tannins. Tannins are naturally occurring chemicals that contribute to the taste, mouthfeel, appearance, and flavor profile of a whiskey. To counteract this effect, one distillery stated during their interview that they could investigate potentially increasing their use of French oak because it has the most intense tannin structure. This distillery also noted that it is possible to use different types of wood to age whiskey. While bourbon is required to use new, charred oak barrels by law, there are many different varieties of oak that can be used. American white oak is used predominantly because historically, barrels were used as storage during transfer and oak was plentiful, while also holding liquid well. This distillery states that for bourbon, “white oak makes a delicious product.” However, other distilleries are beginning to experiment with using different types of oak for aging, such as pin oak, as well as other types of wood, such as mesquite and pecan.

Recommendation 4: Implement closed-loop water cooling systems

A report by the Beverage Industry Environmental Roundtable (BIER) in 2011 revealed that distilleries have the highest water-use ratio range of all beverage sectors, ranging from 9.11 to 63.06 liters of water per liter of spirit (Cooper, 2012). The distilling process is water intensive, and improving water efficiency is an important target in improving environmental sustainability for distillers. A distillery believes that one way to reduce their carbon footprint and save water is to implement technology that cools liquids efficiently. Because the whiskey-making process requires heating the inputs, any energy used to cool is putting more carbon into the atmosphere.

One avenue to reduce water usage is to implement a closed-loop water system, which is a recirculating system that employs the use of coolant fluids in a closed-loop setup to exchange heat from various industrial and commercial processes (Marrone, 2019). Compared to a traditional previous single pass setup where water was used only once before dumping, a closed water loop system will recycle water through the system repeatedly. This system minimizes water consumption by reusing the water continuously, while also limiting the release of contaminants into bodies of water which may be harmful to aquatic life (Marrone, 2019).

Negligible amounts of water are lost during operations, amounting to just a few gallons per year, which can help distilleries comply with water reduction targets and reducing wastewater disposal costs.

Recommendation 5: Greater focus on reducing carbon footprint

Through literature review and qualitative interviews, four main recommendations for reducing the carbon footprint of distilleries are using more renewable energy, reducing fossil fuel usage, recycling glass, conserving energy, and implementing carbon dioxide containment systems.

Switching to Renewable Energy

Converting operations to electricity and utilizing renewable energy can reduce a distillery's carbon footprint. In their interview, one distillery stated that they could reduce their carbon footprint by switching to renewable energy sources during the production process. For example, distilleries could use electricity sourced from wind or solar instead of a gas-fired boiler to generate steam. This can be done by investing in solar panels on site at the distillery and entering long term contracts with local utility providers to purchase electricity from certified renewable sources with zero greenhouse gas emissions. Diageo's new Kentucky distillery models the possibility of investing in renewable energy and will supply their renewable electricity from Inter-County Energy and East Kentucky Power Cooperative (Diageo, 2020).

Reducing Fossil Fuel Usage

Distilleries can reduce their fossil fuel usage by transitioning their operations from using fossil fuels to renewable electricity. This can be done by converting traditional natural gas-fired boilers to electrode boilers and switching to electric vehicles charged by renewable energy. Electrode boilers can replace the heating requirements that natural gas boilers currently fulfill by using renewable electricity. Similarly, vehicles operating at the distillery can be converted to electric vehicles. However, an important consideration is that natural gas provides an efficient form of heat relative to the amount of carbon dioxide it emits, so using electrode boilers in combination with electricity from fossil fuel-fired power plants could cancel out the benefits. Thus, it is important to replace fossil fuels with electricity from renewable sources.

Distilleries can also reduce their transportation footprint by working with local farmers. Transportation plays a significant role in the food and beverage industry because food is often shipped long distance. An analysis of plant-based products such as grains shows that transportation contributes to over 16% of the life cycle emissions (Wakeland, 2012). This is especially influenced by the mode of transportation. If grains are shipped via air, transportation will be a larger contributor to total life cycle emissions. Furthermore, while some grains may be shipped via ocean transport, which is generally low emissions per unit freight, the road transportation generates similar amounts of emissions as the longer ocean segment. Thus, working with local farmers can significantly reduce the emissions resulting from the transportation of grains. There are also ancillary benefits, such as increasing local biodiversity and supporting local businesses in the area of the distillery.

Recycling Glass

Reusing and recycling glass has enormous environmental benefits because it can be recycled over and over without loss of quality or purity. Furthermore, recycling glass has enormous environmental benefits, including reducing carbon emissions, raw material consumption, energy use, and waste. Landfills received almost 7 million tons of glass waste in 2015, but for every six tons of recycled used container glass, carbon emissions can be reduced by one ton ("Sustainable Glass," 2019). Additionally, for every 10% of recycled glass used during the manufacturing process, energy costs drop 2-3%, particulates produced drop by 8%, nitrogen oxide drop by 4%, and sulfur oxides drop by 10% (“Why Recycle Glass,” 2021). One distillery believes that a meaningful avenue of sustainability centers around reusing glass bottles that hold the whiskey when sold to consumers. They stated that making the bottle and transporting it is where their environmental footprint is the greatest. There are a variety of ways that could lower the environmental footprint in packaging and shipping whiskey. Furthermore, recycled glass could be used up to 50 times, if done efficiently.

A distillery in western Colorado has successfully implemented a bottle reuse system. The Jack Rabbit Hill produces a vodka that is delivered to restaurants for consumption. Then, a designated delivery team that brings the vodka to the restaurants will collect the empty bottles. These bottles are brought back to the distillery where they are cleaned, refilled, and re-delivered to the bars (Castrodale, 2019). While this system may face problems at a larger scale, distilleries could investigate navigating a system that promotes reusing and recycling glass as a method of reducing their overall carbon footprint.

Conservation

The cheapest and most efficient way to reduce emissions is to save energy. Conservation is the act of reducing the consumption of energy by producing or using less of it, and there are a number of ways that distilleries can increase their energy efficiency.

First, distilleries can reduce their heating and cooling needs by creating buildings with lower roofs and utilizing more efficient insulation. Diageo’s new carbon neutral distillery in Lebanon features lower roofs, which reduce the heating and cooling needs because less volume needs to be climate controlled. In addition, proper insulation can save energy. During the whiskey-making process where heat is required, insulation on distillation tanks can save 10-25% in energy costs (Syneffex, n.d.).

Second, distilleries can implement an infusion-mashing process to reduce their carbon footprint. This process was explained by a distillery during the interview since they currently utilize this technique. In whiskey production, the mash bill goes through a cooking process that gelatinizes the starches and converts it to sugar. The addition of yeast then converts the sugar to alcohol. Generally, it only takes 79-85°C to gelatinize the starches in the grains, but most distilleries bring the mash bill up to a boil (100°C). Furthermore, different grains have different gelatinization temperatures: corn at 85°C, wheat and rye at 68-71°C, and barley at 63-68°C. However, it is unnecessary to gelatinize by boiling, so this distillery saves energy by heating only to 85°C to cook their corn first. Then, after a lower volume of corn is heated to 85°C, they allow it to cool and add the wheat/rye, and then allow it to cool further and add the barley. This makes the process more efficient because they only heat what is necessary to the highest temperature and add the rest of the grains without any additional energy expenditure. This process does not require a large investment, and distilleries can reduce their heating bill and reduce their carbon footprint by simply monitoring the temperature during the cooking process.

PART V: CONCLUSION

XI. Conclusion

The impact of climate change will likely extend to the whiskey industry in the United States. The purpose of this study was to gather information on how distilleries in the United States were being impacted by climate change and formulate potential adaptation methods. In summary, distilleries are cognizant of the effects of climate change and how it can affect their operations. Four of the most prevalent themes throughout the interviews were climate change and its effect on grain variety/production, aging whiskey in the warehouses, wood used for barrel aging, and water access. The final theme, adaptation, was prevalent throughout all the previous four themes and was already implemented, in the process of being implemented, or part of the response plan to a climate-related trigger.

Most distilleries have identified parts of the whiskey-making process that are impacted the most by climate and have a grasp of the scale of the impact. The themes identified and discussed are mostly related to the whiskey-making process. Beyond the assertion that the relationship between climate and the whiskey-process is the most direct, there are a few potential reasons to explain this. First, the questions asked were more focused towards understanding how climate affects the whiskey-making process. Second, the personnel interviewed are closely tied to the whiskey-making process, which lends itself more to that perspective than if the interviewees were from a different department of the distillery. Finally, the distilleries interviewed may not be a representative sample of all the types of distilleries; all five distilleries were in Texas or Kentucky, and distilleries in different regions could have different experiences.

Overall, the distilleries are aware of some of the potential effects of climate change and how it could impact their industry. However, some distilleries are unsure about how material the impact would be. One distillery mentioned that if climate change did affect their industry, they would have to adapt. But because climate change is a slow-moving phenomenon, they cannot determine if the change will be meaningful enough to influence how they produce or age their whiskey. Another distillery mentioned that they do foresee climate change will influence the way they make whiskey, but there is a chance it "happens at such a slow rate that it might not be as big of a deal." Even still, the distilleries who held this sentiment had adaptation methods in mind and committed to proactive measures that focus on positive environmental sustainability. Being aware of the effects of climate change and taking steps to reduce carbon emissions are the most effective ways of creating a sustainable distillery and promoting stewardship of the resources the earth provides. Investing in the future of whiskey production may be necessary to preserve the integrity and longevity of the spirit many have grown to love.

APPENDIX

Appendix A: Figure 1

("Impact of climate changes on crop yields of winter rye in Halle (southeastern Germany), 1901 to 1980", 1992)

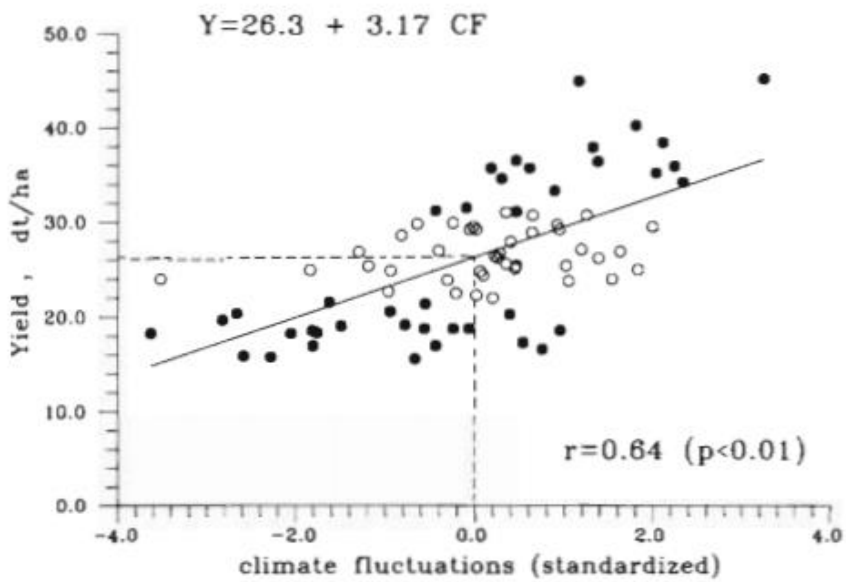
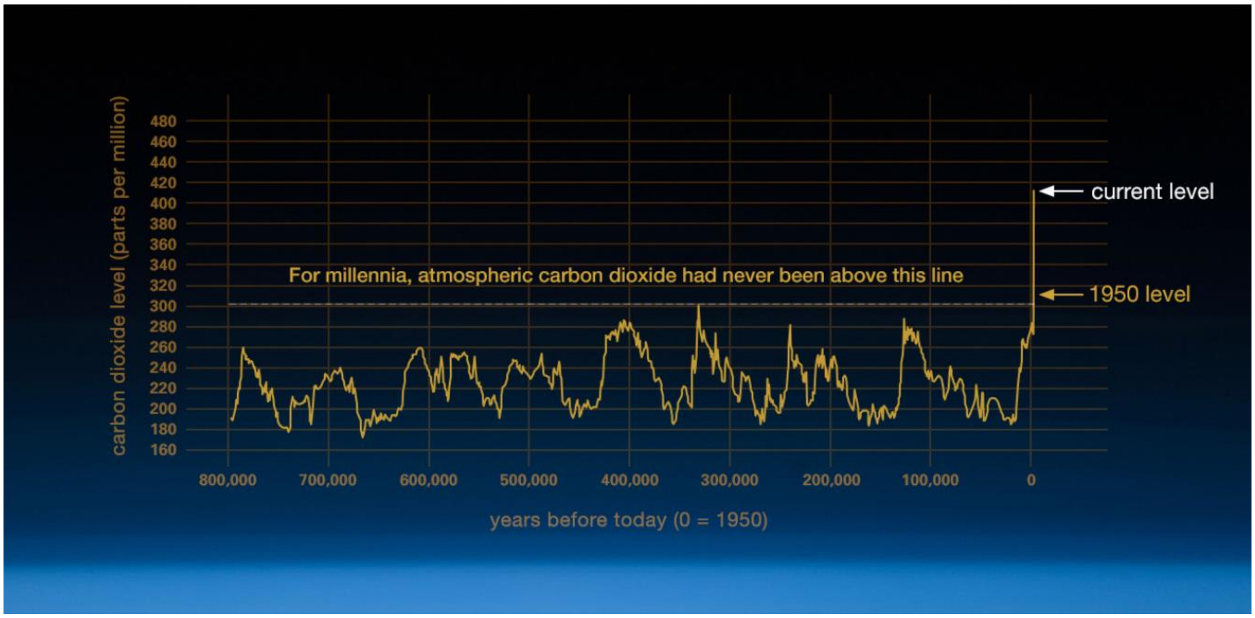


Fig. 6. Linear approximation of the correlation between climate fluctuations (CF) and winter-rye-yields (Y) in Halle, 1901 to 1980, on the basis of monthly weighted climate variables. Filled circles indicate low and high yields

Appendix B: Figure 2

("Climate Change: How Do We Know?", n.d.)



Appendix C: Interview Questions

1. What is your background?
    a. Professional career
    b. Current Role
    c. Years in profession
2. How did you get involved in the whiskey industry?
3. Currently, how does climate affect the whiskey-making process for you?
    a. Follow-up question based on response
4. Do you foresee climate change influencing the way that whiskey is made?
    a. Why or why not?

5. Have you experienced extreme temperature variability and yield fluctuations?
    a. If yes, how has it affected your distillery?
6. Do you have any prevention or adaptation methods in mind for climate change?

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Billy Li was born in Bryan, Texas on January 22, 1998. He moved with his family to Austin, Texas at a young age and has lived there ever since. Billy enrolled in the McCombs School of Business and the Plan II Honors program at the University of Texas at Austin in the Fall of 2016. During his time at UT, Billy was accepted to the Master in Professional Accounting (MPA) program, a five-year integrated masters program, to go along with his Plan II degree. He had the opportunity to study abroad in Buenos Aires through the MPA program and was involved in various organizations on campus. Most notably, Billy was involved in Asian American Campus Ministry on the executive board, and served as President of the Texas Blazers, an honorary service organization that serves as the official hosts of the University of Texas. Billy plans to graduate in May 2021 and to join McKinsey & Company as a Business Analyst in the Fall 2021. He hopes to continue exploring his interest in climate change and reducing carbon emissions throughout his career.