Analysis of the Effect of Climate Change on Cultivation of Arabica Coffee (*Coffea arabica*)

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By

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On my honor as a University student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments.

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Introduction

Climate change is almost certainly the defining issue of the current generation, and the leading contributor to climate change is carbon dioxide (NASA, 2014; IPCC 2017). Agriculture is one of the most vulnerable industries to climate change due to commonplace practices that rely on fertilizers, reduce crop diversity, and neglect soil health. Changing weather patterns will cause flooding and droughts, as well as affect changes in crop and livestock viability, pests, weeds, and pathogens (Union of Concerned Scientists, 2019). Cultivation of the arabica coffee plant, which is now categorized as an endangered species, is among the most highly threatened agricultural practices. Technologies, such as carbon capture, utilization and storage (CCUS) have the potential to mediate a portion of greenhouse gas (GHG) emissions. Even with the implementation of CCUS technologies, farmers must still consider adaptation techniques to reduce the potential for extinction of Coffea arabica.

The International Energy Agency (IEA) reported a 2.3% increase in global energy demand in 2018, resulting in a 1.7% increase in CO_2 emissions from energy-related processes (Jungcurt, 2019). Energy-related CO_2 discharges from the United States alone amounted to 5,268 million metric tons in 2018 (EIA, 2019). Industries such as cement, steel, and chemicals production all release CO_2 during manufacturing, but quite literally lay the foundation for global infrastructure development (IEA, 2019).

While carbon emissions are an inherent part of day-to-day life, CCUS technologies are at the forefront of carbon emission mitigation techniques. CCUS is the process of capturing, transporting, and re-using or storing CO_2 to prevent its release to the atmosphere. A reduction in the concentration of CO_2 in the atmosphere will lower the CO_2 loading rate on Earth that is known as a main cause of climate change.

Changes in the climate caused by GHG emissions are projected by experts to limit, if not fully eliminate, agricultural arabica coffee cultivation, which is a staple to society on a global scale (Davis, Dr. Aaron P, 2017). Coffee consumption was at its highest during the 2017/18 fiscal year, with the global population consuming 161.74 million 60kg bags (ICO, 2019). Investigation of the potential effect of climate change on growth of Coffea arabica is vital to not only the global population, but farmers and the livelihoods of their communities. Greater than 90% of coffee production is located in developing countries (Ponte, 2002), and the residents of these areas are found to be extremely vulnerable to climate change. This paper will explore the negative effects of climate change on the cultivation of Arabica coffee in developing nations.

Case Context

Climate change is defined as an array of environmental perturbations brought on notably by the release of greenhouse gases. Carbon dioxide atoms, the most abundant greenhouse gas, are able to absorb infrared (IR) radiation and trap heat in the Earth's atmosphere. This IR radiation excites the CO_2 molecules, which then re-emit the radiation back towards Earth's surface. This process results in the entrapment of heat in the atmosphere and the warming of the planet (UCAR 2012).

Perturbations resulting from climate change are observed in the form of modified precipitation and biotic patterns typically in the form of more erratic and drastic weather events, higher overall global temperatures, altered direction, strength, and steadiness of prevailing global wind patterns, and more (Trigo & Gimeno, 2009). One of the most notable effects the increasing carbon dioxide emission rate has had on the planet is escalating average annual temperature. Since 1900, Earth's average surface temperature has increased approximately 1.4 °F, while carbon dioxide emissions have also increased (NASA, 2014). Not only are greenhouse gases becoming much more concentrated in the earth's atmosphere, but they are also increasing in concentration in oceans. This leads to ocean acidification and increasing ocean temperatures resulting in sea level rise, among other negative outcomes.

World-wide CO_2 emissions, specifically those from burning fossil fuels, have risen over the past five years according to the World Resource Institute (Levin, 2018). Energy production accounts for 72 percent of manmade greenhouse gas emissions by sector globally, with major contributions resulting from electricity and heat, transportation, manufacturing and construction (C2ES, 2019). The Environmental Protection Agency reports that about 27.5% of the CO_2 emitted in the US comes from electricity generation (United States Environmental Protection Agency, 2018), and energy need is inflating at a rapid pace. CCUS technologies implemented at energy generation facilities have the potential to drastically reduce this trend.

Already, CCUS machinery is rapidly establishing their place in today's society. As of the year 2019, the International Energy Agency reports 30 million tons (Mt) of CO_2 emissions capture from 16 industrial-scale CCUS operating at facilities that produce fertilizer, steel, hydrogen, or process natural gas (IEA, 2019). Not only are CCUS technologies desirable due to their positive environmental impact, but they also generate desired public relations for the facilities in which they are implemented. Tension often results between industrial facilities and the communities they are located in due to health and environmental concerns, and publicized employment of a CCUS scrubber will aid in the mitigation of said tension.

The release of greenhouse gases can be largely attributed to energy production technologies and facilities that burns fossil fuels. Ever since the industrial revolution in the late 1700's, annual carbon emissions have been increasing as society develops across the globe.

These emissions are the leading cause of climate change, and are resulting in drastic shifts in the global ecosystem.

Even in areas without a net decrease in suitable land area for coffee cultivation, there is the potential for many barriers to the production of Arabica coffee in the future. For example, Costa Rica is projected to experience geographical shifts in suitable locations for arabica coffee production, but will not experience an overall loss in suitable land area. That being said, economic growth of Costa Rica is leading to the urbanization of suitable coffee cultivation areas to become suburban, so existing infrastructure will prevent the utilization of land for coffee production. This will, in turn, lead to the country experiencing pressure to move coffee production to higher elevations in areas currently covered by forest that have the potential to remain viable for coffee production much longer. This will lead to a loss of important biodiversity and problems related to water quality and quality in metropolitan areas (Coto-Fonseca et al., 2017).

Changes to the operation of Earth's biotic patterns are cause for concern in many aspects, but the agricultural industry is especially vulnerable. Developing nations that cultivate and harvest Arabica coffee are potentially among the most vulnerable.

The Relationship between Climate Change and Coffee

Changing climate conditions have already led to an increase in poor harvests of Arabica coffee, and land suitable for coffee growth is expected to deteriorate globally. It is vital to identify what communities are most vulnerable to climate change deteriorating *Coffea arabica* cultivation conditions. Gathering an understanding of the manner in which coffee farmers personally view the impact of climate change is critical to generating a representation of the social impacts of climate change.

Nations producing arabica coffee with a Human Development Index (HDI), developed by the United Nations (WPR, 2019), of less than 0.80 and spanning near the equator, such as Vietnam and Costa Rica, are the focus of this study. In 1999/2000, Vietnam was the world's second largest producer of coffee (Ponte, 2002) and has three zones particularly vulnerable to climate change: the Mekong Delta, the central highlands, and Son La (Parker, Bourgoin, Martinez-Valle, & Läderach, 2019). Scientists from the University of Costa Rica stress that coffee production in Costa Rica is an important economic and cultural market that will experience a drastic shift in suitable locations by the year 2070 (Coto-Fonseca, Rojas, & Molina-Murillo, 2017). It is necessary to explore the impact of climate change on the production of Arabica coffee in developing countries that rely on the crop as a staple of their economy due to extensive research providing troubling projections for its production in the future.

Science, technology, and society (STS) techniques must be utilized to solve the "grand challenge" of climate change as explained by Wiebe Bijker (2017). Bijker argues that technological intervention can improve the world for the next generation by referencing policy implemented by governments, research agencies, and economic organizations that are now focusing on the potential social impacts of technology. The effects of climate change will most likely be felt by Generation Z and their children. It is an issue whose cause began during industrialization, but whose effects will mostly impact future generations of coffee farmers.

The relationship between climate change and coffee farmers will be explored using the technological determinism STS theory developed by Thorstein Veblen (Papageorgiou & Michaelides, 2016) as interpreted by Oliver Brette. Brette states, "Veblen analyses institutional change as an emergent effect of the dynamics of interactions between instincts, institutions and the infrastructural conditions (Brette, 2003)." This framework emphasizes the deterministic effect of technology on societal norms and cultures of affected areas based upon its interaction with situational circumstance and ideology of localities impacted. It details the idea that technology shapes society, not the other way around. Specifically, descriptive technological determinism is used as a means to focus on the force driving sociotechnical change (Wyatt, 2008).

Veblen stresses the conversion from initial cause and eventual effect through the process of causation (Brette, 2003). Brette stresses that other than causation, the second main theory of Veblen's technological determinism is the fact that the outcome remains outside of the range of knowledge. Climate models can accurately predict when and where coffee can and will be produced, but the fact of the matter is that it's very difficult to pinpoint exactly how this will change the lives of farmers. The human reaction relationship to climate challenges is very complicated, which is why gathering data relating to farmer perspective is vital.

In this specific case of arabica coffee harvesting in developing nations, farmers are left with virtually no option but to adapt according to the effects of climate change that they experience. Climate change is a direct result of technological utilization of fossil fuels to generate energy, and this technology has a clear impact on coffee farmers in developing nations. It is an issue whose cause began during industrialization, but whose effects are fully impacting future generations and require a response.

Research Question and Methods

The research question that was explored is as follows: What are the expected repercussions of climate change on the cultivation and harvest of coffee, specifically Coffea arabica, and resulting effect on society at an international level?

The relationship between climate change and arabica coffee cultivation is extremely complicated and required extensive research from many perspectives. To ensure the breadth of research was suitable to tackling such a complex issue at a national level, primary sources were utilized to gather first-hand perspectives on the effect of climate change on the cultivation of *Coffea arabica*. Farmers are the first to feel change in the agricultural sector, and their perception of climate change decides the manner in its effect is felt by consumers when it comes to their cultivated products.

Scientific evidence of the effect of climate change on the cultivation of Arabica coffee was compiled utilizing academic articles and journals. Personal accounts such as surveys, interviews, focus groups and other forms of evidence detailed in academic papers were utilized to construct a meaningful account describing the effect of climate change on the production of *Coffea arabica*. Research was focused on major Arabica coffee-producing locations near the equator that have an HDI of less than 0.80 and therefore are more sensitive to economic impacts in the agricultural sector brought on by climate change.

Many academic articles were utilized in this analysis. Ten case studies were the main source of information analyzed, spanning various countries. Five of the ten academic articles provided a global examination of geographical suitability of land for Arabica coffee production. The remaining five academic articles provided primary data from residents of the following countries: Vietnam, Costa Rica, Uganda, Brazil, Mexico, Puerto Rico, and Ghana.

Outside of academic articles and journals detailing the position of farmers in their local communities, staff at local businesses that source their coffee beans directly from these countries were surveyed utilizing a Google Poll. MudHouse Café, Shenandoah Joe coffee roasters, Grit Coffee, Greenberry's, Milli Coffee Roasters, and Snowing in Space Coffee Bar are the local coffee locations from which I inquired about their sourcing and connections related to coffee beans. These accounts of primary data were grouped based on perceived risk and knowledge of climate change to conclude vulnerability and address any educational needs related to climate change. Information gathered was used to provide insight and a contrasting view from the perspective of developing communities producing *Coffea arabica*.

Results and Discussion

Arabica coffee is a very vulnerable crop as it requires a lot of precipitation at specific time intervals and a relatively narrow temperature range for growth (Mayer, 2013). Temperature and precipitation changes are expected to result in current areas suitable for growth becoming unable to support cultivation. A global temperature rise of 2 degrees Celsius would result in a reduction of two-thirds of the present suitable elevations (Vermeulen, 2013). Wild Arabica coffee is projected to substantially decline in numbers globally, if not become fully extinct by 2080, and its survival is paramount to the endurance of the coffee industry as a whole (Davis, 2017). Many farmers have perceived climate change posing a barrier to their success and expect major difficulties in the future. The analysis performed in this thesis is attributed to data gathered from Vietnam, Costa Rica, Uganda, Brazil, Mexico, Puerto Rico, and Ghana specifically, with additional data from a global point of view. Local Charlottesville coffee sourcers reinforce this view through perspectives detailed during interviews and through surveys.

Projected climate trends of Puerto Rican *Coffee arabica* growth were generated that identified necessary bioclimatic parameters for coffee growth, and a bioclimatic suitability model was generated using geographic information systems (GIS). It is projected that climate conditions of Puerto Rico will no longer reach optimal parameters for Coffea arabica within the years 2041-2070 (Fain, 2018). Scientists from the University of Costa Rica stress that coffee production in Costa Rica is an important economic and cultural market that will experience a major shift in suitable locations by the year 2070 (Coto-Fonseca, 2017). Figure 1 shows a global perspective in the shift of coffee production suitability by 2050.

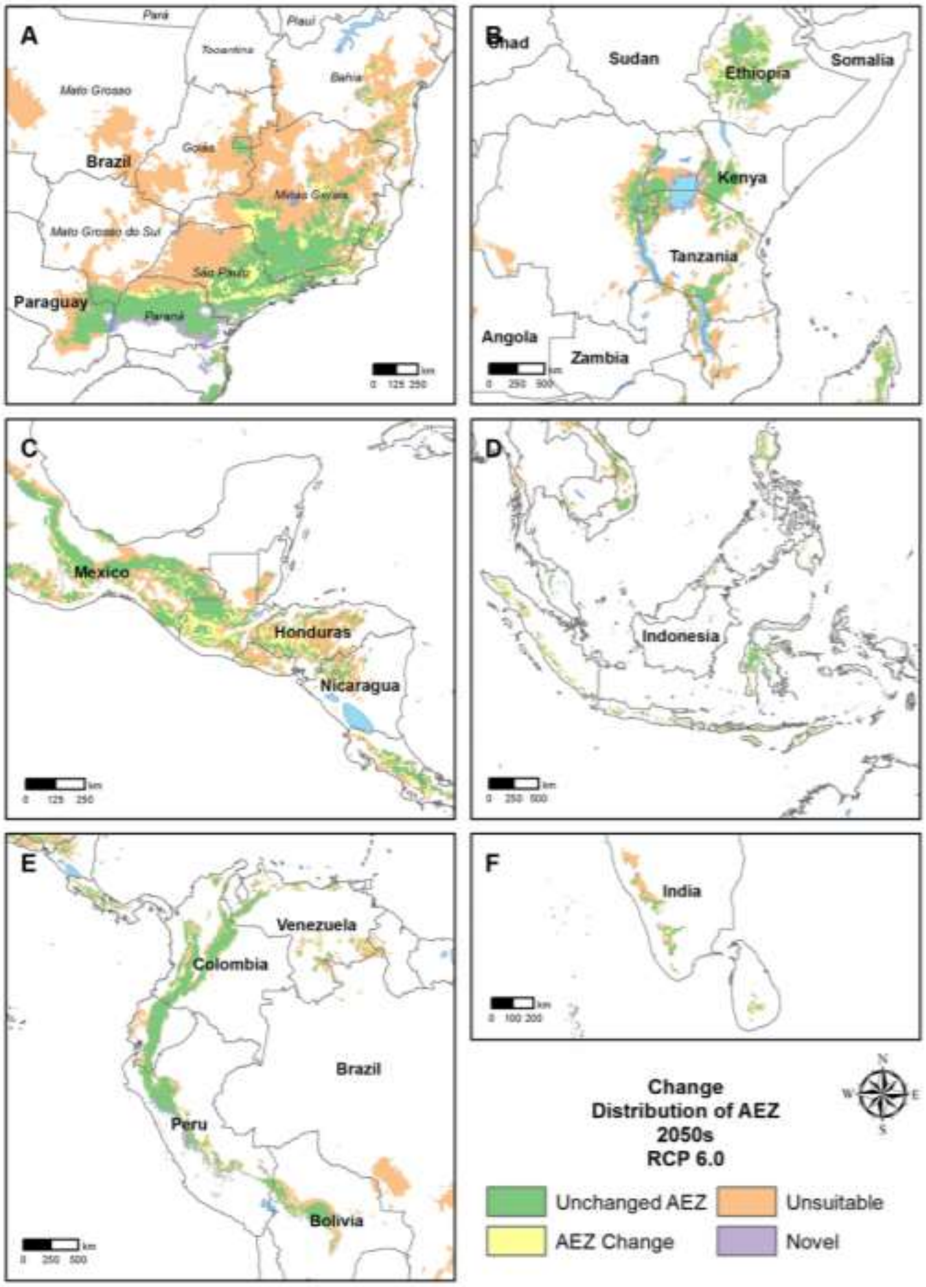

Figure 1. Map of coffee land suitability changes by the 2050s. Diagram by Christian Bunn, et. al., 2015. Public Domain. Retrieved online from PLOS ONE. (Bunn, 2015).

Not only will increasing global temperatures reduce the amount of suitable land for coffee production, but it will also allow for greater prevalence of destructive coffee pests. Juliana

Jaramillo, a Columbia native scientist with Leibniz University of Hannover, Germany, stresses that increased temperature has proven to increase the survival of the coffee berry borer (*Hypothenemus hampei*), the most prevalent coffee pest. Jaramillo states that increasing temperatures will lead to "serious consequences… rendering production very difficult" for countries such as Brazil, Mexico, and Uganda (Mayer, 2013).

It is necessary to address the economic ties of climate change to socioeconomically vulnerable farmers as well as gathering technical data exploring the effect of climate change on the cultivation of arabica coffee. Economic growth of Costa Rica is leading to the urbanization of suitable coffee cultivation areas to become suburban, which will lead to the country experiencing pressure to move coffee production to more limited elevations in forested areas due to their potential to remain viable for coffee production much longer than other areas (Coto-Fonseca, 2017). This will lead to a loss of important biodiversity and problems related to water quality and quality in metropolitan areas.

The majority of *Coffea arabica* production spans a slim band of lands tracing the equator, see *Figure 2* (Varcho, 2008), and the bulk of these countries are categorized as "developing countries". As conditions continue to change, the potential for families in these locations to lose their livelihoods as the climate becomes too poor for cultivation and harvest increases. Research shows that impoverished coffee farmers are of the highest vulnerability to climate change (Mayer, 2013). Having an understanding of the viewpoint of farmers themselves on the impact of climate change is critical to generating a representation of the social impacts of climate change. Farmers are the first to feel the change on the agricultural sector brought on by climate change, and their perception of climate change decides the manner in which climate change is felt by consumers when it comes to their cultivated products.

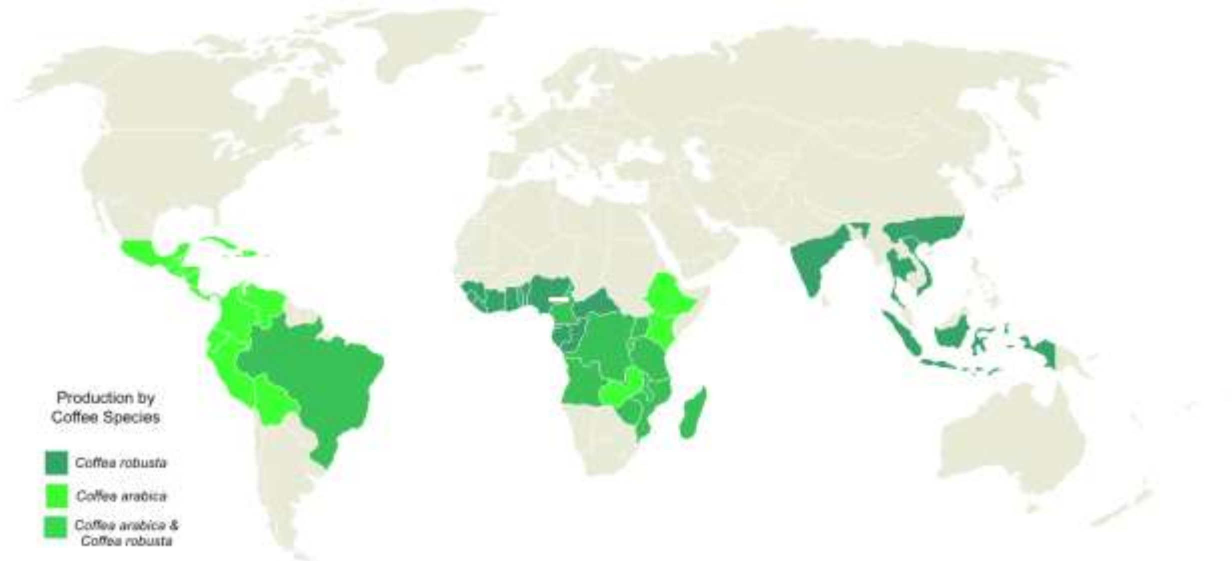

Figure 2. Map of coffee production by country. Diagram by Brhaspati, 2007. Public Domain. Retrieved online from Ohio State Pressbooks (Varcho, 2008)

Ninety-three percent of farmers in the Lawra district of Ghana have perceived climate risk based on information gathered by focus groups and questionnaires, and the focus of concern is on resources available to the farmers based on socio-economic class (Ndamani & Watanabe, 2017).

Agriculture adaptations to climate change may cause land-use impacts, and the prospect of moving to a new location to follow suitable land poses social and economic issues, especially for poor farmers (Ndamani & Watanabe, 2017). Global changes in coffee growth will require adaptation that may result in nomadic behavior to ensure sustainable cultivation (Mayer, 2013). Shifting suitability of location for coffee production may force farmers to transplant their lives from one location to another, but coffee farmers tend to have limited resources and the prospect of such an investment is completely unrealistic (Mayer, 2013).

Six local Charlottesville coffee shops were surveyed via Google Forms to gauge perception of the effect of climate change on their individual businesses. The businesses included in this survey were MudHouse Coffee, Shenandoah Joe, Grit Coffee, Greenberry's, Milli Coffee Roasters, and Snowing in Space Coffee Bar. Four major questions were asked: "In what countries/locations are your Arabica coffee beans grown?", "Have you perceived any difference in coffee bean availability, price, or quality over the past 5-10 years?", "Have you perceived any difference in coffee bean availability, price, or quality over the past 5-10 years that is attributed to the effects of climate change?", "Do you believe climate change will in the future affect your ability to source Arabica coffee?", and then a space was left to indicate any other points of information the respondent wanted to share.

All responses indicated a perceived difference in coffee bean availability, price, or quality over the past 5-10 years. Three indicated the belief that this difference was not due to the effects of climate change, but only one response indicated the belief that climate change will not in the future affect their ability to source Arabica coffee. Specified locations of coffee bean sourcing included central South America, Africa, and Indonesia.

A Snowing in Space representative expressed future concerns over "limited availability of quality beans at affordable prices, variances in the beans themselves … increased human rights issues in countries/areas where coffee is heavily relied upon for income." They also stated their belief that the "ultimate effects of climate change on coffee … will only be statistically identifiable/discernible from our perspective over a much longer time horizon. Although you might get different feedback from individuals in different geographic pockets." Developed communities are more sheltered from the repercussions of climate change on the coffee industry due to their ability to diversify sourcing and increased access to technology.

Intense innovation and economic growth has led to severe unintended consequences that bring a growing awareness of the need to innovate responsibly. The theory of technological determinism details how implemented technology causes unavoidable shifts in society. Experts suggest using horizon scanning along with emerging trend analysis to ensure the sustainability of technology and innovation in the future (Owen et. al., 2009). Horizon scanning, emerging issue identification by scanning literature and synthesizing through knowledge management approaches, and problem formulation, the initial qualitative phase of risk assessment defining who might be at risk and from what are introduced as two important techniques to manage innovation in the future.

Regulation can be very useful in supporting sustainable initiatives, but happens too slowly to be reliable when tackling technology-driven issues of the environment. This coupled with the speed at which data arises proving the health or environmental detriment an innovation pose. "Regulation is destined to play catch up," the Owen states (2009).

The connection between climate change and cultivation of coffee is a very complex issue. In hindsight, the scope of research is nearly too wide to cover. It is difficult to gather enough information to fully explain the characters and relationships at play both scientifically and socially. Not only is gathering information difficult, but there are limitations on first hand perspectives and primary data due to the geographical distance and language barriers between myself and farmers of Arabica coffee. There are not many local coffee shops that have employees with firsthand knowledge of coffee bean sourcing.

Measures need to be taken to educate and aid farmers of coffee beans. The coffee industry generates an immense amount of revenue globally, and many consumers are unaware of its delicate state. Extensive research has been performed on increasing the sustainability of coffee farming and increasing efficiency of cultivation techniques, and farmers must be educated on their options to preserve their crop into the future. The implementation of technologies such as CCUS systems have the potential to mitigate climate change by reducing the release of greenhouse gases globally. Engineers have the responsibility to ensure they consider the environmental impact of their research and technologies.

My plan for the future is to become a highly regarded and influential environmental engineer. Having an understanding of how prominent technologies can cause a butterfly effect altering the balance of other industries as well as the climate is paramount to my success. I must always keep in mind how fortunate countries like the United States are to practically have a buffer when it comes to the effects of environmental issues due to our economic state.

Conclusion

Being mindful that technologies seemingly extremely beneficial to the human race may have extreme unintended consequences is vital to being a responsible engineer. Climate change brought on by industrialization and technological innovation causing massive combustion of fossil fuels resulting in the release of greenhouse gases is undeniably going to have a detrimental effect on the cultivation of *Coffea arabica*. Coffee farmers spanning close to the equator living in countries with an HDI of less than 0.8 are likely to experience life-altering changes to their crop in the near future, and tend to have an understanding that climate change is the root of many issues relating to harvest and cultivation. Local coffee shops understand that climate change is going to change the way they do business, but generally are not as concerned as the socioeconomically vulnerable farmers.

Adaptation, planning and innovation show promise as means to manage the impacts of climate change within the agricultural sector. Climate change education for those involved in the Puerto Rican coffee industry, knowledge sharing networks, mitigation strategies, and cooperatives are all recommended strategies to boost awareness and efficiency in managing agriculture (Fain, 2018). Global communication between farmers can provide a network of knowledge for those effected by climate change to collaborate and implement strategies that are proven to work. The Arabica coffee industry will not survive if everything continues in a business as usual manner. Thoughtful mitigation and sustainable solutions must be implemented to ensure the survivability of *Coffea arabica*.

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