Bryant University

HONORS THESIS

Effects of Climate Change on The Agricultural Supply Chain in the American Northeast

By Brian Villanueva

ADVISOR • John Visich

EDITORIAL REVIEWER • Paul Roselli

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ABSTRACT

The purpose of this project is to investigate the effects that climate change will have on the agricultural supply chain in the Northeast United States. The goal is to provide risk mitigation methods to farmers and supply chain professionals for how to combat the rapidly changing environmental status quo. This was investigated by surveying 21 farmers about their opinions about the current state of farming and their optimism or pessimism on the future of farming. The findings reflected a great concern for the future of farming despite many alarming signals about the increasing intensity of storms. The conclusion was that supply chain managers should prioritize climate change risk indicators when selecting suppliers to combat risk and give a competitive advantage against unprepared competition. By taking a more proactive approach, many companies will be more prepared to "weather the storm."

INTRODUCTION

The global market has been no stranger to supply chain disruptions during the past decade. From floods, droughts and natural disasters, more emphasis than ever is being put on managing risk within the supply chain. In the next ten years, the global supply chain management market is expected to grow from $25 billion to $72 billion (Appendix A) (Precedence Research, 2023). This has been fueled by an increase in technologies that allow companies to take control of their supply chains such as cloud computing, IoT, 5G and 3D printing. These technological drivers have allowed supply chain experts to make more precise decisions and cut costs within companies.

This industry growth comes at a crucial turning point for the global market as natural disasters are increasing in frequency and severity. Meteorologists cannot predict when the next major disaster will occur in time for supply chain professionals to make the proper adjustments. Therefore, natural disasters have always been a factor that people within the supply chain industry have chosen to accept instead of address. These risks cannot simply be "accepted" anymore due to the increasing severity and frequency of these storms and weather events. A large storm can wipe out an entire company's source of raw material and lead to missed customer orders or even closure. The industry needs to adapt and plan for these changes so that customers and companies can find stability in an unstable time.

This paper will start by investigating the current literature available, both locally and internationally, in order to learn about the past research that has been done on this topic. This literature can be applied to any similar problems that the Northeast is facing. To draw conclusions about the opinions of northeast farmers, a survey was sent out.

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LITERATURE REVIEW

The agricultural supply chain is an integrated system of networks that aims to control risk while transporting goods, share information, and transfer money upstream to the source of raw materials. The main upstream partner will be the farmer growing the crop and harvesting to sell to the downstream partners. The agricultural supply chain is unique because it can be very difficult to accurately forecast production for a given crop harvest. Many things can go wrong, which can dramatically change the output of the yield, including major weather events, disease, and mismanagement. In addition, many items produced must be transported quickly to provide fresh goods to the downstream supply chain partners. Any delay in transportation could cause the food to spoil and become worthless. Regional events such as weather, political unrest or other events can impact the ability of companies to move goods to the intended customers. The literature review will use some research about manufacturing firms in order to receive information about how other firms navigate adversity. This will allow all options to be considered when researching this very complex issue.

This research project is centered around the effects of rising temperatures on the agriculture supply chain within the New England area. The literature review has been focused on practical examples of climate change impacting the supply chain such as biodiversity loss, food security, innovative technologies, demand for healthier foods, geopolitical uncertainties, inflation and disruptions (Miranda, 2023). The goal was to collect articles that depict how agriculture was impacted by weather disasters. After completing this research, it is clear that climate change will have a disastrous effect on the agriculture supply chain in the next 20 years because of increasing weather-related natural disasters. Therefore, companies need to diversify geographic risk and make emergency plans to create a more flexible supply chain. The purpose of this research is to investigate how agriculture was impacted by weather disasters; investigate supply chain impacts; and offer solutions to stakeholders.

Climate Change and Biodiversity Loss

Climate risk exposure is becoming a more critical issue when choosing a location to conduct business. Certain regions on planet Earth are more susceptible to major weather events that can impact the flow of goods and information. By incorporating this risk into the decision-

making processes, the proactive measures can prevent millions in lost sales in the future. This is noticeably clear when viewing the droughts currently facing the Chinese agricultural system.

Climate-risk exposure is becoming more prominent as climate change grows to become more of a problem. The method of transportation is also a key factor to consider, not just the geographic location. Natural disasters are causing major damage not only to the supply chain, but the physical manufacturing and collection facilities for raw materials. MunichRe, the German reinsurer claims that its calculations show global losses caused by natural disasters came to "$280 billion compared with $210 billion in 2020 and $166 billion in 2019" (As cited in Beals, 2022, para. 12). Despite these shocks causing significant harm, it is not always obvious that companies will adjust their strategy. Companies are more likely to change strategy after they themselves have experienced a shock. A challenge they often find difficult is convincing channel partners of this impending risk if the other partners have not experienced the same problems (Pankratz & Schiller, 2021). This shows the human reaction to ignore each of these significant weather events as "random" when in fact they are not random at all but connected. Certain parts of the world experience different levels of risk when it comes to natural disasters (Appendix B & C). Whether the location is close to a body of water or commonly experienced droughts, there are many factors that can make a supplier undesirable due to its climate-risk exposure.

When choosing a supplier, it is important that a company in a high climate risk part of the world tries to get insurance or funding to restore their business, they may find it difficult since the disaster will be fresh in people's minds. (Woetzel et. al, 2020). More importantly, literature has shown that climate change has a measurable impact on agricultural production. In Gambia, it was proven that climate change was reducing the productivity of crops drastically. It is expected that the "production of all agricultural commodities will decline by an average of 35%" by 2055 (Belford et. al, 2022, p.1). Connecting back to the Northeast area, the region has seen a shift for when their harvest is ready. A Rhode Island farmer said, "back in 1980 when I first started planting, I would harvest my last crop of broccoli in early November. Now it is commonly late November and sometimes even early December" (Rhode

Island Division of Statewide Planning, P.1). Climate change will not only affect the production of crops, but it will also impact the entities that help bring the crops to the dinner table. Studies from the Rhode Island Statewide Planning Program (2015; 2016) prove that rising sea levels will cause increased storm surges. This will lead to more road closures as the years go by, which causes delays in shipments. If companies do not act to limit their risk exposure, they are limiting their ability to serve their customers as consistently as possible. Missed shipments can lead to unsatisfied customers and lost connections.

Food Security at Risk Due to Growing Demand

At a time when it seems like farming is becoming ever more difficult, it is also becoming equally important. By the year 2050, the world population is expected to hit 9.7 billion people. As a result, agricultural production will need to increase 20-30% in order to meet the growing demand (Miranda, 2023). This highlights the importance of ensuring the continuance of this important industry and the necessity of providing proper guidance to farmers about how to combat climate change.

The literature stresses the devastating effects the drought is having on local Chinese communities in which water has become scarcer. The population in China has ballooned over 1.4 billion people meaning that the population requires more resources to sustain itself. Everything from land, farming equipment and fertilizer has seen an increase in prices as the industry scrambles to keep up with demand. The growing population has also put a strain on its water resources in an already dry region of the world. Since there are more people, there is less water going towards agriculture and industry which can cause significant delays in production (Hoang et. al, 2022; Swanson & Bradsher, 2022). Companies should use information like this to avoid doing business in areas of the world where food production is already strained.

The Need to Adopt Innovative Strategies

The literature also touched on an innovative way to fight these climate-induced risks within the supply chain. By introducing agtech to suppliers, farmers can diversify their crops so that they are less susceptible to major weather events. This will make more resilient biodiversity within agriculture so that all crops are not destroyed in the case of major events. According to

Hoang et. al (2022) Agtech could be an integral part in feeding the world's growing population and eliminating food scarcity. The more supply available, the lower the costs for the consumers. By diversifying the crop yield, companies will be better prepared for the future. A major food producer, Danone with headquarters in France, pledged to create demand for a variety of seeds in order to create a more biodiverse agricultural system (as cited in Saladino, 2022). This initiative will not only help the company, but also help the world produce food for everyone. The US Department of Agriculture (2017) also recommends pursuing irrigation as a form of combating increasing temperatures (US Department of Agriculture, 2017). This will allow farms to reduce their reliance on rain and keep a steady stream of nutrients to their crops. There are many solutions for combating these increasing risks within the agricultural world. With looming climate impacts, it appears that now is the time to incorporate them at every level.

Agricultural technology has progressed substantially since the early days of farming. Farmers now, more than ever, have more control over the yield of their crops. Agricultural Intensification is defined as harnessing ecosystem services for food security. Ecosystem services are processes provided by the planting of agricultural products, such as supporting services (soil formation), regulating services (pest control), provisioning services (food production), and cultural services (recreation) (Bommarco et al., 2023). Agricultural intensification can occur when farmers utilize technology and biological enhancers to improve the crop's yield. Using better technology such as improved equipment, pesticides, irrigation, etc. Theoretically, farmers can utilize an unlimited amount of these enhancers to achieve their maximum yield of 100%, but this is not economically feasible. At a certain point, the cost of enhancers outweighs the benefit of the increased yield. (Appendix D). Since a farmer will never reach their "theoretical" yield, the next is the "attainable" yield. This is the yield that farmers could likely reach assuming that they have proper access to resources in order to enhance production. Farmers in third-world countries may see a benefit to their crop yield if they were to use enhancers, but if they do not have access, they will not be able to achieve this goal. The "actual" is the realistic standard for farmers across socio-economic backgrounds to achieve. This provides a realistic basis for farmers to set their standards. This number will vary based on weather, crop types, and geography. A typical farmer in a developed country

only yields approximately 80% of their crops before it becomes uneconomic to continue to seek higher yields (Bommarco et al., 2023).

Due to the green revolution, which occurred in developed countries during the 20th century, there was a span of great technological advances that made and continue to make it possible to cultivate crops in ways that generated higher yields. The methods used include irrigation, pesticides, and modern farming technology. Technology allowed farmers to work further away from typical farming locations and control their production more accurately. Therefore, a simplified agricultural environment was created which had drastic effects for biodiversity. The agricultural climate crisis cannot simply be prevented by increasing yields because the crisis has a negative impact on the world around us, thereby worsening the crisis further. The optimal solution is to be inside the "safe zone", or where the amount of intensification is balanced by a healthy amount of simplicity (Appendix E) (Bommarco et al., 2023).

When laid out on a small scale, farmers can adapt easily to increasing weather unpredictability. In Asian countries, many farmers have incorporated these strategies to combat droughts. The Eastern Asian region of the world has been combating droughts for the past few decades and struggled with an increasing population. In order to combat this problem, the country has switched to greenhouses on smaller-scale productions (Asian Development Bank, 2022). Greenhouses allow the farmer to control the environment around the plant and retain water for the plants to reuse. By providing a roof and walls, the crops will be protected from extreme elements, producing more consistent results that are essential for a farmer's bottom line. The other solution is drip irrigation which aims to reduce the amount of that water evaporates into the air (Asian Development Bank, 2022). Using pipes and hoses, a small amount of water can be released at frequent times to allow the plant to receive just the amount of water that it needs. This reduces water waste and ensures that the plants are maximizing the water provided for them.

In contrast, large scale operations have more options that farm, and supply chain participants can use to ensure the security of the agricultural supply chain. Supply chain integration is the main takeaway because in order to identify risks, you must know where to look for those risks. Supply chain integration is the process of bringing together the MRP systems of many

different companies that contribute to the agricultural supply chain of the final product. By thinking beyond one's own site, they are able to find large scale solutions that can help predict unpredictability more accurately. Once a map of suppliers is made, a comprehensive assessment of each site's risks can be laid out. These risks are based on a multitude of factors including vulnerability to natural disaster, local economic indices, geopolitical risk factors, proximity to suppliers, access to energy and labor (Boyson et. al, 2022). This information can be used to reallocate the amount of reliance in one geographic region or one company. By diversifying a company's dealings, there is less risk that a singular natural disaster or weather event will impact a company's production or pricing. Anything that halts production can be disastrous for a company.

These solutions cannot be driven externally, and in order to make the worldwide agricultural supply chain more risk-averse, change needs to come from within these companies. This can be very challenging because often supply chain managers and buyers are not incentivized to prepare for the future. Further, employees know that they will most likely change companies within a few years. U.S workers have an average tenure of about 4.1 years with a single employer (Coursera, 2023). Employees are focused on making short-term decisions because they will not be rewarded if they only plan for the future. This short-term mindset is one of the main factors that limits the ability for change within companies to become more climate-risk averse.

However, it has also been shown that employees tend to be more optimistic when thinking about the future of the company. Since they have poured so much time and effort into the company, it is hard for people to think about the unexpected. Surveys show that 81% of subjects overestimate their business prospects by believing that the likelihood of success is 70% or even higher. Moreover, managers believe that failure is less likely to happen to them than to others (Zhang et. Al, 2023). Companies should create incentive plans that better represent the future of their company rather than focusing on present day performance. The incentive plans should be aligned with meeting risk mitigation metrics in order to properly compensate employees and protect the company from climate change. This way the company will be better equipped to tackle all challenges.

Geopolitical Uncertainties

In the Roman empire, the term "dictatorship" meant a temporary grant of absolute power to a single leader to handle the crisis (Guriev & Treisman, 2022). As climate change intensifies, countries will face mounting political pressure. As natural disasters tear apart a country, people will call upon their government for aid when enduring hardship. In times of great panic and turmoil, sometimes countries turn towards dictators who have a powerful presence. These dictators use fear in order to gain and maintain control over their populations. They spin people's fear into support for their new cause. This rise in dictatorship can have a huge impact on the agricultural supply chain due to the political risk involved. Under a dictatorship, change can happen very quickly. Since there is only one person in charge, there is no long-drawn-out process for change. Hypothetically, trade could be banned on a random day or company property could be seized. Companies try to avoid doing business in these risky environments, but this may become a challenge in this new world of impacts from climate change.

Inflation and Increasing Operating Costs

The literature revealed significant details about the rising cost of doing business and how companies need to increase spending to better prepare for disruptions. In a trade journal article by Stauffer (2022), the author suggests that an increased investment in insurance is the easiest way to offset weather risk. This insurance will offset the costs of any disruptions that a company may face and will make it easier to weather the storm (Stauffer, 2022). It was noted in a study by Beals (2022) that only half of all-natural disaster impacted property was insured. Another source by Hodgson (2022) suggests that reducing dependence on just-in-time delivery will help companies be more flexible. Nina Seega, from the University of Cambridge's Institute for Sustainability Leadership, said "just in time" supply chains were particularly vulnerable "if you can work to allow some slack in the system, that will create a more resilient system overall," she said (as cited in Hodgson, 2022, para. 11).

The literature revealed a significant financial impact when geographic regions are disrupted by weather events. Pankratz & Schiller (2021) investigated the impact on shipping costs when weather related shocks occur. The authors found that heat and flooding incidents have a negative correlation with the financial performance of suppliers. This also has financial

impacts on downstream customers as well (Pankratz & Schiller, 2021). By pursuing risk-mitigation efforts now, it could save companies from having to pay higher prices for shipping in the future.

Logistics Issues Creating Disruptions

The focus for this investigation was acquiring articles about specific natural disasters and shifts in climate affecting the various parts of the supply chain. The investigation by Doefler (2021) looked at the "Texas Freeze" which shutdown networks within the state for over a month. In this disaster, Union Pacific told its customers that they could expect to see a 72-hour delay on all shipments (Doefler, 2021). In a world of interconnected supply chains, having this delay caused massive delays in transportation for downstream customers. Other research by Swanson & Bradsher (2022) investigated the increasing droughts in Southwestern China and the effects it still has on production within the region. The drought has caused many factories to lose power, because Southwestern China relies heavily on hydropower. This has caused companies to look elsewhere to find the goods they need (Swanson & Bradsher, 2022). These two events depict the nature in which these disruptions will impact the supply chain. Companies will have to adjust to delays in production or be flexible about transportation routing when making decisions about where to source materials. This is further reinforced by the research by Woetzel et. al (2020) that claims that the risk of supply chain disruption in the semiconductor industry will rise 2-4 times by 2040 from hurricanes. The growing risk throughout the world will affect manufacturing for years to come. To prioritize the safety of the employees within the transportation supply chain, companies are forced to halt production in cases of extreme weather. This stoppage can significantly impact on a company's ability to keep up with demand. The literature by Pankratz & Schiller (2021) and Doefler (2021), halting production can cost millions of dollars in lost revenue. The growing risk throughout the world will affect manufacturing in the future.

The Direction of Future Research

This literature contributes evidence that climate change is posing a huge risk to the survival of supply chains in every company worldwide. It stresses the importance of geo diversifying and offers strategies to plan for these issues. Climate change will affect the agriculture supply chain in the next 20 years by increasing weather-related natural disasters. Companies need to

diversify geographic risk and make emergency plans to create a more flexible supply chain. This strength of the literature comes from strong worldwide examples of major supply chain disruptions. The weakness is that there is very little literature available that provides quantitative data to provide wide ranging conclusions on the subject. Future research needs studies that provide quantitative data which can be analyzed to draw conclusions about the subject matter.

METHODOLOGY

Research Methodology

This research project will investigate the impacts of climate change on the agricultural supply chain. In order to investigate this topic, surveys will be conducted with people in industry to see the impacts of climate change. Likert scale questions will be included to measure the level of concern these industry members have about climate change. Research will also be conducted about the potential solutions which can be proposed through the survey. By allowing industry members to give their opinions about the solutions, a consensus opinion will be developed. The research project will also work with New England Departments of Agriculture across the many regions to gain contacts within the industry. This will allow the survey to correspond to a plethora of participants and give it a diverse audience of opinions. The survey will also be distributed through LinkedIn by connecting with industry contacts to gain their opinions on the subject matter. This methodology is appropriate for this type of research because it is very hard to project future outcomes especially related to a volatile field such as weather. During the data collection portion of this investigation over 300 inquiries were sent to farms via their company website, Facebook or LinkedIn. There were 39 responses to the survey indicating a 13% response rate. Unfortunately, only 21 of the 39 responses were usable due to incomplete responses. This means that out of the 300 inquiries, the response rate was approximately 7%. Many farms in the New England area were not included in the data collection trial, so there may be unaccounted bias which causes difficulty when drawing conclusions about the status of Northeast agriculture. The data collection will be backed up by research from academic journals in order to ensure reliability for readers and increase general application use for this paper. The goal is to find sources that are specific to the New England area, but other geographic areas will be used to provide context to this area.

There may be similar challenges in other places around the world that can be contextualized within New England. Regions that share similar climates could share information to avoid these risks.

Potential Research Issues & Ethical Considerations

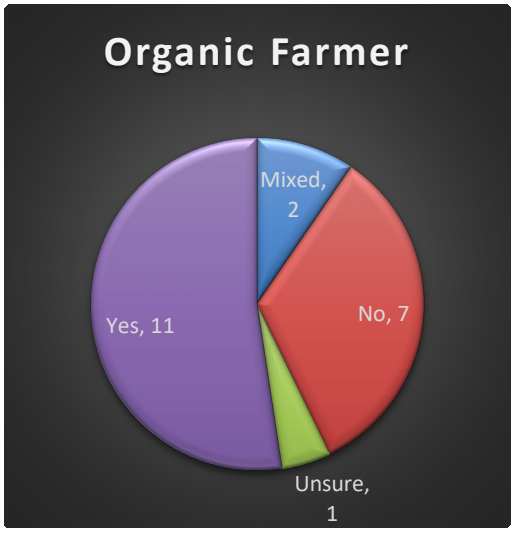
One potential issue that was anticipated by this project was not getting support from local and state agencies. When finding survey participants, it would make the collection much easier if there was a database of industry members that would be willing to answer questions about the challenges of climate change. This difficulty could be overcome by individually reaching out to industry members on LinkedIn to get responses. Another issue is determining criteria for who is considered an industry member. The intention of the survey is to find people who have industry knowledge and experience with the agricultural supply chain. The survey will focus on supply chain professionals at food companies and farmers. The only ethical issue that could be considered is if an industry member shares confidential financial information about their company. The survey has been conducted in such a way that there are no relevant identifying documents that could expose any confidential information. This research project has been approved by the IRB board to conduct these surveys.

SURVEY RESULTS

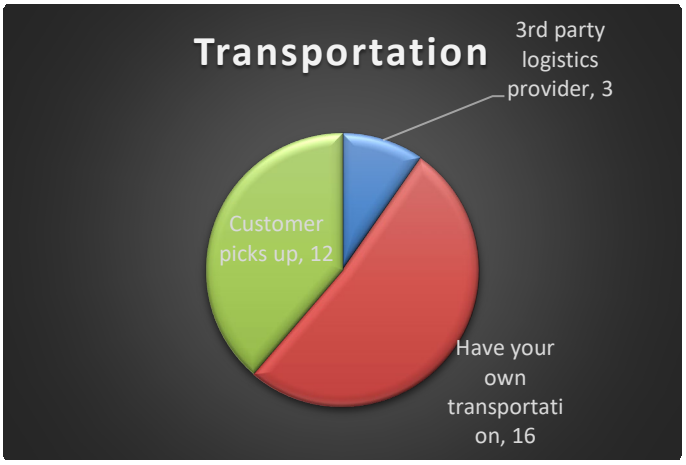
Demographics

Demographics were an important part of this survey because it helps identify the issues facing different groups of farmers. Not all farms are built the same, so it is important to categorize each response. It was noted that the majority of respondents were from either Rhode Island or Connecticut, making up 48% and 24% of the responses respectively. The remaining were split up evenly with two responses each between New Hampshire, New York, and Massachusetts. While this may lead to a slight bias in geographic location, we do not believe this will have a significant impact on the survey results.

Of these 21 survey respondents, 16 owned and operated the farm they were employed at. The survey was sent to smaller farmers, so this is to be expected. Many small farms do not have a large number of employees and therefore all business is conducted by the owner. Over 50% of the responses were from organic farmers. According to the Environmental Protection Agency, organic farming is "food grown and processed using no synthetic fertilizers or pesticides. Pesticides derived from natural sources (such as biological pesticides) may be used in producing organically grown food" (EPA, 2023). Preserving this type of farming is important because they will be the most exposed to the effects of climate change. By not using pesticides to make their plants more resilient, they can easily be wiped out by a random event. Approximately half of the farmers surveyed produced vegetables. The other respondents produced an assortment of dairy, specialty crops, and fruits.



Transportation is a very crucial element of the agricultural supply chain. Any disruption to transportation can cause huge problems for farms. They may have to discard expiring food or pay more to get their product shipped out. Of the respondents, 16 had some form of their own transportation to ship to distributors or directly to stores. Other respondents have a process of customer pickup or 3rd party logistics. Most customers had a combination of a few different transportation methods so as not to be too reliant on one sole source of income. Self-transportation can have positive and negative connotations. On the one hand, having your own transportation can provide more control over the agricultural supply chain. You do not need to rely on another company. On the other hand, a small farm may not be able



to handle a supply chain disruption such as a labor shortage or truck breakdown. While working on a micro level, these small disruptions can have huge impacts on business.

The farmers surveyed sell most of their products locally (less than 150 miles radius). The average percentage of locally sold products is 86%. Approximately 16% of goods are sold outside of this local radius (domestic and international). This is a healthy sign for the industry because sourcing locally can help reduce supply chain disruptions. There is less risk because they are passing through less geographic areas.

Job Difficulty and Hardships

As the effects of climate change create chaos around the world, it was important to get the perspective of local farmers to see the direction they see the industry heading. Most farmers agreed that the work is not getting easier. Eighty-Six percent of the respondents claimed that their job had remained at the same difficulty or became more challenging because of environmental conditions. This is to be expected as the randomness and frequency of storms has been making planning harder. Surprisingly, many farmers have not experienced an increase in cancellations or delays when sending out their products. In the last 5 years, 81% of farmers claim that there has not been an increase in cancellations. This is surprising because one would expect the more frequent storms to cause many more delays to the supply chain in the Northeast. As it turns out, since many small farmers use their own transportation system, they are able to avoid these delays, because there is no conglomerate company that needs to reschedule the delivery. The small farmer can simply take the products when it is safe to do so.

Many farmers will have to face more hardships in the future. In the last year, there was a terrible drought in Rhode Island that caused many farmers to lose much of their crop yield. This can have drastic consequences for a business, especially when occurring more frequently. On the other hand, many respondents also claimed that there was a lot of flooding in the past year. When looking at these two claims, it can be very confusing to comprehend. How can farmers be complaining about droughts and flooding? These responses just speak to the weather unpredictability to come in the future. These unpredictable weather conditions have impacted the bottom lines of these farms. Survey respondents complained of lowered

revenue due to damaged crop yield and COVID-19. The most interesting result was a respondent who claimed that they had their first-ever crop insurance payout. In previous years, paying the insurance had been a way of risk mitigation and preparedness, but they had never expected to use it. These insurance payouts could be a sign of times to come as these conditions continue to worsen.

The international pandemic had a far-reaching impact on every industry imaginable. As a result, many farmers were affected. Before Covid, 81.8% of farmers claimed that their transportation was "somewhat reliable" or better. During Covid, that figure dropped to 59.1% due to the many restrictions and lockdowns put in place. After Covid, that figure returned to 77.3%, but fewer people claimed that the transportation was extremely reliable. The pandemic could not have come at a worse time as business were grappling with the impacts of climate change.

Incorporated Solutions

Many of the farmers have already incorporated solutions to combat these increasingly unpredictable weather conditions. One of the solutions to fight these risks is increased irrigation capacities. If there is ever a time of drought, the farm can quickly scale to water the crops using stored water. Another strategy is to utilize more short-term crops to reduce the risk of weather impacts. If a storm wipes out a crop yield, the farm can quickly act to replant and harvest to reduce the long-term financial impacts. In addition to short term crops, more resilient crops can be planted to withstand the weather conditions. This will allow the farm to become less dependent on the weather and be able to reduce their crop risk. These solutions only work on a micro-level, however. Every farm cannot produce only the crops that provide the least risk, and some crops need to be produced to provide the food that consumers want. In order to combat this, farmers have been increasing their crop diversity, mixing in high risk and low risk crops. These actions allow the farms to have a steady income for the low-risk crops while profiting from the high-risk crops.

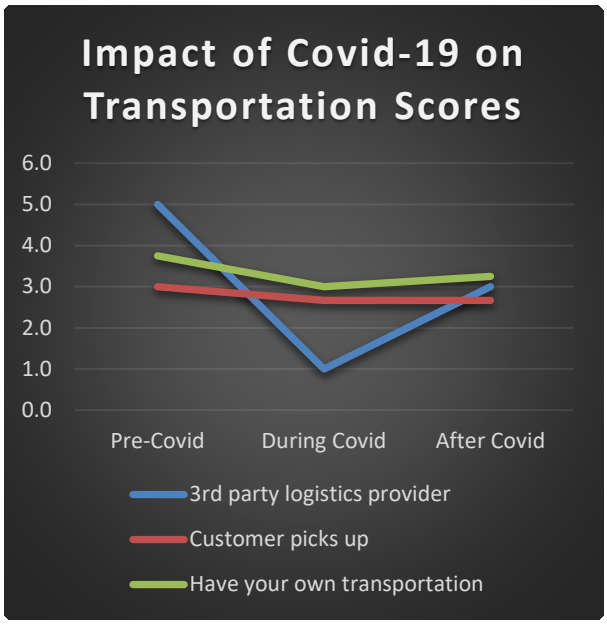
FINDINGS

It is crucial that solutions are available for supply chain planners and buyers to combat the risk associated with climate change as the effects go beyond the impact on the population.

The future poses new threats and challenges that the supply chain needs to face. Companies have to adapt to these new global guidelines if they want to take a proactive approach to their future. It has become abundantly clear that our population does not have the means or the will to combat climate change. These solutions are not aimed at curtailing the main causes of climate change, but rather the adaptations farmers and those in the supply chain industry need to make in order to survive in business.

Looking at the geographic location of the survey respondents, it is clear that these farms have faced major challenges in the past years. In Connecticut and Rhode Island, many farmers claimed that major flooding had caused both financial and agricultural losses in the past year. Connecticut is typically a wetter state with an annual average of 50.3 inches per year which ranks fourth in the country (Current Results, 2024). This year showed a 29% increase from the average as the state saw 65 inches of rain (Pitts, 2023). This posed challenges for farmers after flooding ruined many of their crops. In contrast, farms that were north of Connecticut experienced the opposite in terms of rainfall. The surveyed farmers from Massachusetts, New Hampshire, New York and Rhode Island all claimed droughts were a large contributor to financial hardship. Upon further research, it becomes even more confusing when every one of these states reported historical highs in rainfall for 2023. After diving deeper, it is obvious that the farms may have been referring to the extreme droughts in 2022. In the graph provided by the National Integrated Drought Information System, it is clear that the Northeast experienced severe droughts during this time period (NIDIS, 2024) (Appendix F). This sudden shift from extreme drought to historical flooding had a huge impact on the agricultural yields for farmers.

In the survey, farmers were asked about the reliability of transportation on a scale of one to five with five being highly reliable. According to the farmers, the average transportation score pre-covid was 3.76, during covid was 3.00 and post-covid was 3.29. The score decreased 20.2% during covid and only recovered 9% after covid. This means that the pandemic has caused irrevocable harm to the transportation system in the Northeast. Farmers are not able to ship their products out on time during a period when weather impacts are expected to be more extreme. When looking at these scores, it is clear that the transportation methods are the main pain point for farmers. Farms that chose to use 3rd party logistics companies had the biggest impact during covid while customer pickup and self-transportation remained stable.



One survey question asked whether or not their supplier could be described as "green." A green supplier takes into account the negative impacts of their operations on the climate. In this question, over half of the respondents did not know whether their supplier was green. This is a huge problem in the industry since many farms have a short-sighted approach to their operations. They do not consider the longevity when choosing suppliers.

CONCLUSION

In conclusion, supply chain managers need to prioritize climate risk when choosing suppliers. This is a challenge for businesses to incorporate because many incentive structures are set up for the short, rather than the long term. Businesses need to ensure that their employees are planning for the future, rather than prioritizing short term gains. Major climate events can

strike at any time and companies need to be prepared to handle these challenges. Being well prepared for a challenge can be a huge competitive advantage for companies while their competitors might be out of commission.

Companies can also avoid risk by having in-house transportation solutions. By relying on third parties to transport goods, a company is putting fate in the hands of a business who doesn't prioritize their needs. By having their own transportation fleet, companies can adjust their strategies quickly to combat any crises they are facing.

The last solution is for companies to invest in agtech solutions to maximize yields and protect crops. These insurance measures can have huge payoffs as weather events become more predictable. By maximizing yields, the company can build in more safety stock to supply to customers whenever there is an industry halting event.

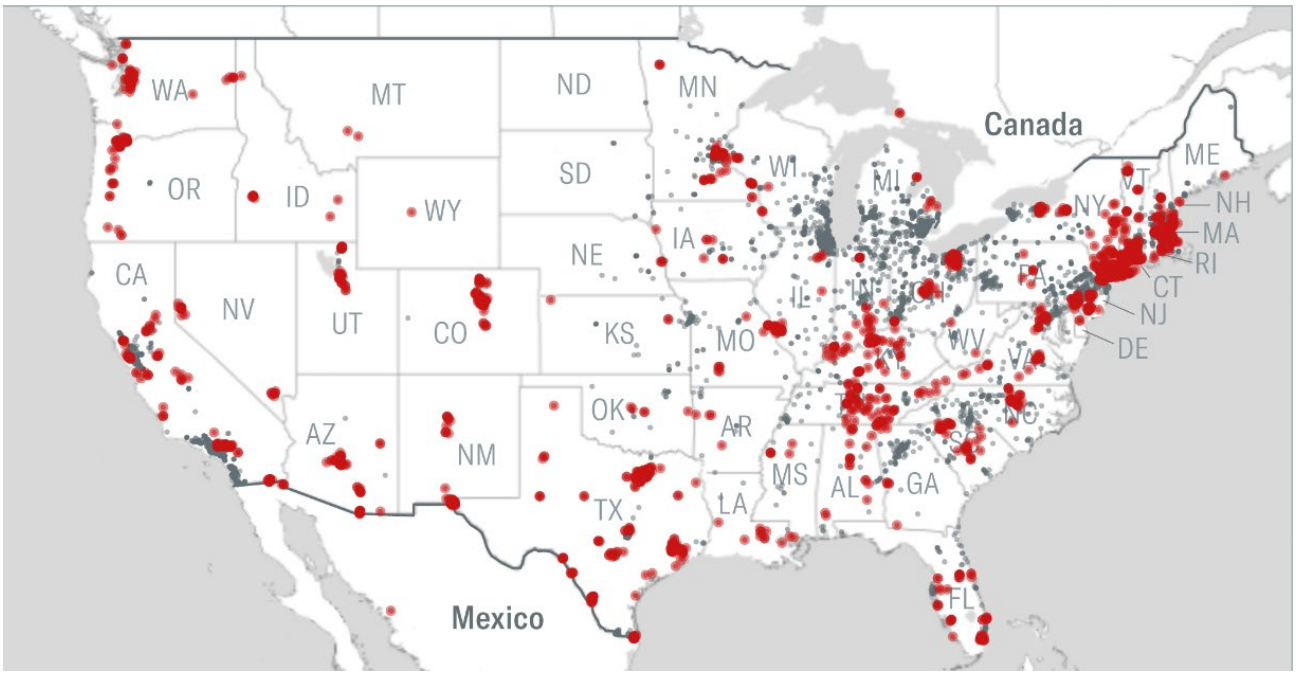
APPENDICES

Appendix A – Supply Chain Management Market Size, 2022 to 2032 (USD Billion)

This graph shows the rise in market size for the supply chain solution industry such as logistics management, transportation planning and analytics, predicting future accuracy, warehouse and inventory management, supply chain optimization, acquisition and sourcing, minimization of waste, manufacturing execution, and pertinent synthesis of business data.

Supply Chain Management Market Size, Industry Report By 2032. (n.d.). Retrieved March 16, 2024, from https://www.precedenceresearch.com/supply-chain-management-market

Appendix B – Supply Chain Sites with the Greatest Climate Risks



The red dots are the United States locations that have experienced the most-extreme climate variability and fastest rates of climate change.

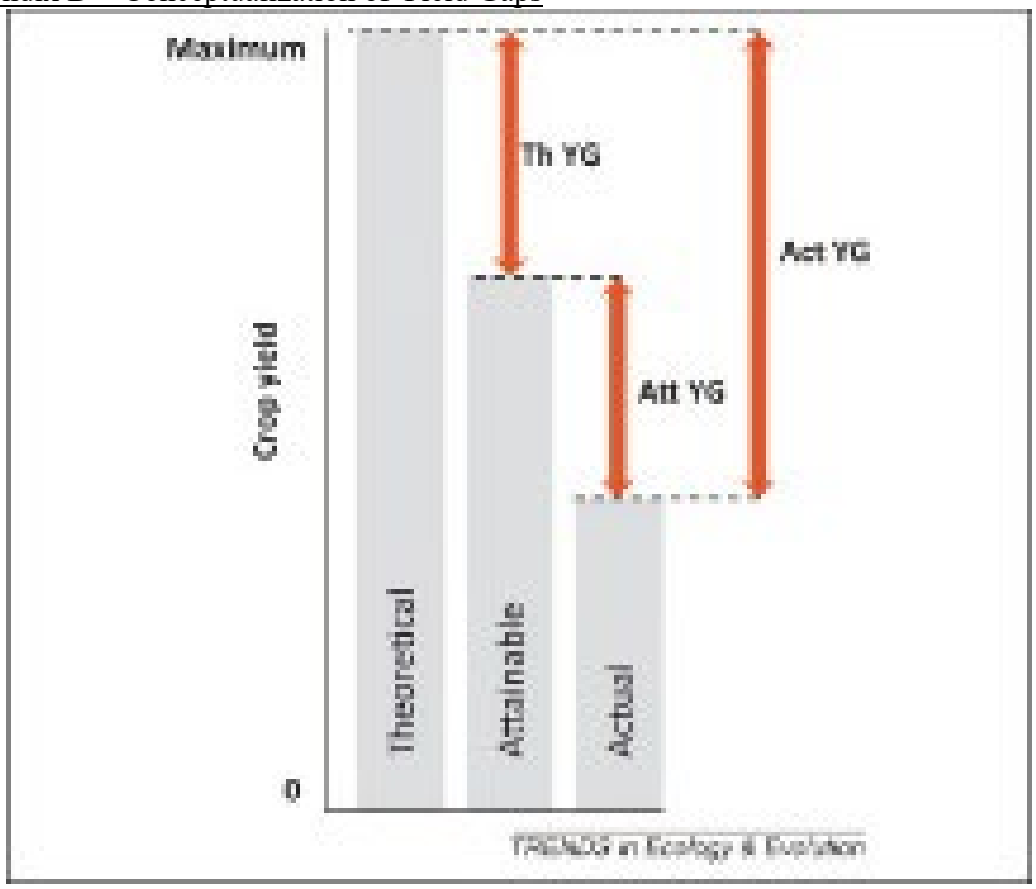
Boyson, S., Gerst, M. D., Guntuka, L., Linton, T., Muraski, G., Vakil, B., & Vakil, S. (2022, May 2). How Exposed Is Your Supply Chain to Climate Risks? *Harvard Business Review*. https://hbr.org/2022/05/how-exposed-is-your-supply-chain-to-climate-risks

Appendix C – The Highest-Risk Supplier Sites in the United States

The red dots are the sites that have experienced the most-extreme climate variability and fastest rates of climate change whose disruption would have a major impact on the revenues of the original equipment manufacturers they supply. These sites also have a low level of resiliency in terms of their preparedness to cope with a climate-related disruption.

Boyson, S., Gerst, M. D., Guntuka, L., Linton, T., Muraski, G., Vakil, B., & Vakil, S. (2022, May 2). How Exposed Is Your Supply Chain to Climate Risks? *Harvard Business Review*. https://hbr.org/2022/05/how-exposed-is-your-supply-chain-to-climate-risks

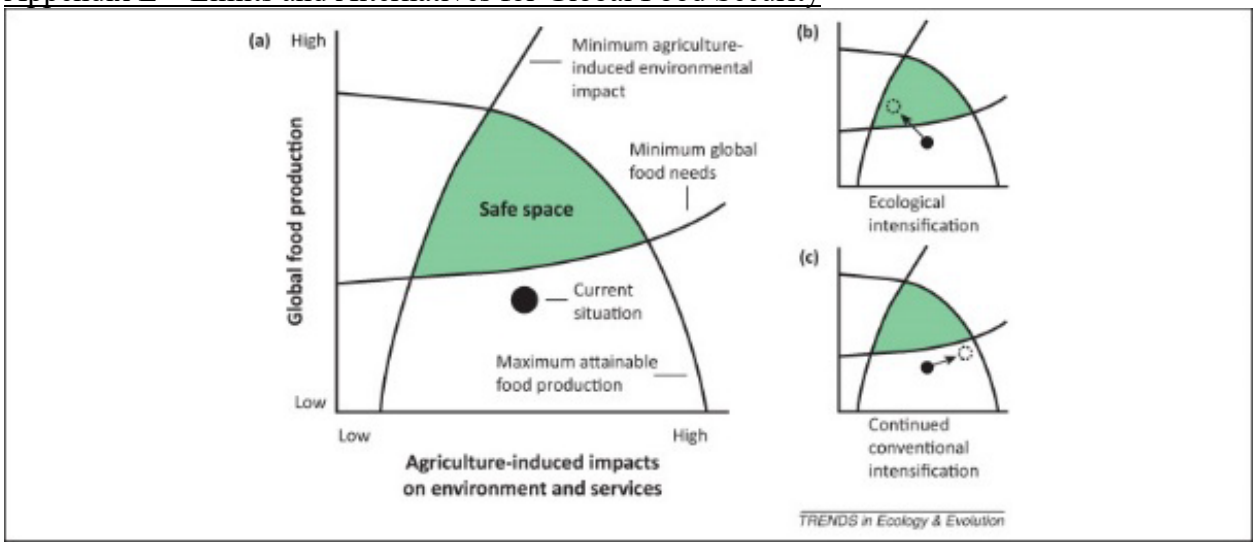
Appendix D – Conceptualization of Yield Gaps



Abbreviations: Th YG, theoretical yield gap that is unavoidable; Att YG, attainable yield gap that is avoidable; and Act YG, actual yield gap (i.e., Th YG + Att YG).

Bommarco, R., Kleijn, D., & Potts, S. G. (2013). Ecological intensification: Harnessing ecosystem services for food security. *Trends in Ecology & Evolution*, *28*(4), 230–238. https://doi.org/10.1016/j.tree.2012.10.012

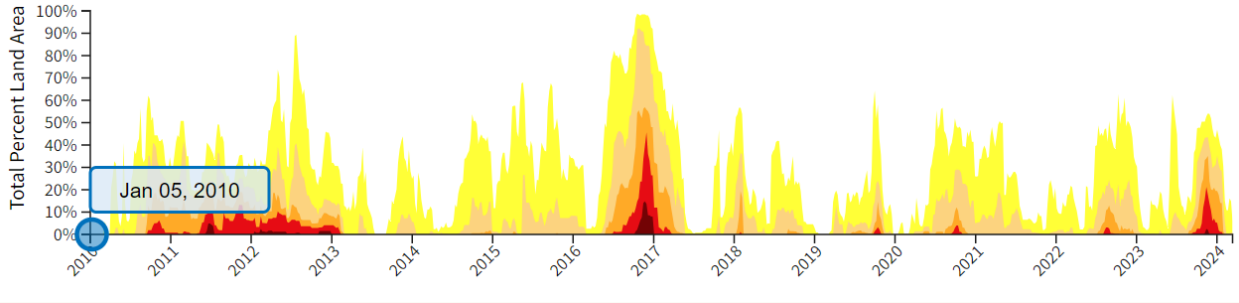
Appendix E – Limits and Alternatives for Global Food Security



Safe area (green) where global food demands are met **(a)**. **(b,c)** show alternative scenarios of ecological (b) and continued conventional (c) intensification. Conventional intensification is expected to move systems towards the right, with increased impacts on ecosystems services and the environment. Even if conventional intensification moved systems into safe space above minimum global food needs, there remains little room for maneuver close to maximum attainable yields, posing increased risks under further environmental change. As systems move towards the right-hand boundary of the safe space, maximum attainable food production is expected to decrease due to degraded ecosystem services. Furthermore, negative impacts on the environment, biodiversity, and other benefits are expected to increase in this direction. A complementary strategy is to widen safe space by dampening demands for food products, such that minimum global needs for agricultural products are lowered.

Bommarco, R., Kleijn, D., & Potts, S. G. (2013). Ecological intensification: Harnessing ecosystem services for food security. *Trends in Ecology & Evolution*, *28*(4), 230–238. https://doi.org/10.1016/j.tree.2012.10.012

Appendix F – Historical Drought Conditions Northeast



This chart shows historical drought conditions in Northeast based on total area in drought.

The darker the color the more intense the drought.

Historical Data and Conditions | Drought.gov. (n.d.). Retrieved March 16, 2024, from

https://www.drought.gov/historical-information

Appendix G – Survey Questions

Position within agricultural industry or place of employment?

Are you an organic farmer?

How long have you been in the agriculture industry?

What is the primary agricultural product you deal with?

What transportation do you utilize to bring product to the customer(s) (Which of the following)
-3rd party logistics provider
-Own transportation
-Customer picks up

Approximately what percentage of your goods are sold locally (Inside 150-mile radius)?

Approximately what percentage of your goods sold domestically (Outside 150-mile radius)?

Approximately what percentage of your goods sold Internationally?

My job has become more difficult in the past 5-10 years due to environmental conditions.
1= Has become significantly easier 5=Has remained the same 10=Has become significantly more difficult
1 2 3 4 5 6 7 8 9 10

There are more delays and cancellations in shipping/transportation compared to 5-10 years.
1=Strongly Disagree 5=Strongly Agree
1 2 3 4 5

I have suffered major financial losses due to a natural disaster?
(Yes/No) If Yes, explain

I have suffered major agricultural losses due to natural disaster.
(Yes/No) If Yes, explain

How reliable was transportation pre-covid?
1=Extremely Unreliable 5=Extremely Reliable
1 2 3 4 5
How reliable was during covid?
1=Extremely Unreliable 5=Extremely Reliable
1 2 3 4 5

How reliable was after covid?
1=Extremely Unreliable 5=Extremely Reliable
1 2 3 4 5

Do you consider your supplier to be "green"
(Yes/No)

I have noticed my supplier make changes to their operations in order to combat climate change.
1=Strongly disagree 5=Strongly agree

1 2 3 4 5

I believe that climate change has had significant impacts on agricultural production at our farm.
1=Strongly disagree 5=Strongly agree

1 2 3 4 5

I am worried that climate change will cause significant impacts to agricultural production in the future on my farm.
1=Strongly disagree 5=Strongly agree

1 2 3 4 5

I have considered changing farming strategies to combat the effects of climate change on my business.
(Yes/No) If Yes, explain

I have considered changing business strategies to combat the effects of climate change on my business.
(Yes/No) If Yes, explain

I have considered changing transportation strategies to combat the effects of climate change on my business.
(Yes/No) If Yes, explain

Additional comments about effects of climate change on transportation.

Additional comments about effects of climate change on farming.

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