Climate Change, Food Systems, and Supply Chains

Jeanette C. Shutay

November 24, 2020

Abstract

Anthropogenic climate change is posing a significant threat to our environment, including our food systems and supply chains. If immediate action is not taken, the average global temperature will likely increase by 4.1 degrees Celsius by 2100. These climate changes will negatively impact biodiversity through forced extinctions and degraded ecosystems and ecosystem services. The degradation of our ecosystems and ecosystem services will have direct effects on our food systems and supply chains. The purpose of this research is to discuss climate change and its impact on our food systems and supply chains. Examples from the Midwest region are provided to demonstrate the significance of the issue. Finally, ways in which these impacts to our food systems can be mitigated are briefly discussed.

Introduction

Anthropogenic climate change pertains to historical changes in temperature and precipitation that are human caused, and these changes pose a significant threat to our environment, including our food systems and supply chains (Schmittner, 2018; Woetzel et al., 2020). Climate change pertains not only to increases in average maximum temperature, but in the amount of variability and extremes in both temperature and precipitation (Esri, 2019; Schmittner, 2018). If immediate action is not taken, the average global temperature will likely increase by 4.1 degrees Celsius by 2100 (Roston & Murray, 2020).

The implications of climate change are many and severe. Climate change impacts biodiversity through forced extinctions (Roberts et al., 2020), degraded ecosystems, and lower quality ecosystem services (Wienhold et. al., 2018). All of these consequences of climate change have complex interactions that ultimately impact our food systems and food chains (Goulson, 2019; Woetzel et al., 2020). We must be able to understand, model, and predict climate change and its potential impacts so that we can design mitigation strategies and increase the resiliency of our environment, our food systems, and our supply chains.

The purpose of this research is to discuss climate change and its impact on our food systems and supply chains. Examples from the Midwest region are provided to demonstrate the significance of the issue. Finally, ways in which these impacts to our food systems can be mitigated are briefly discussed.

The Face of Climate Change

Greenhouse gas emissions are a leading cause of anthropogenic climate change (Roston & Murray, 2020; Schmittner, 2018) and deforestation compounds the problem (Prevedello, Winck, Weber, & Sinervo, 2019). While the climate has naturally changed over time, the rate at which it is changing is increasing exponentially due to human influences (Schmittner, 2018). These changes in temperature are a result of an imbalance in radiative forcing (Esri, 2019; Schmittner, 2018) where earth receives more energy from sunlight than it is capable of radiating back to space. The result of this positive forcing is global warming. Anthropogenic carbon emissions is a cause of this positive forcing (Roston & Murray, 2020; Schmittner, 2018).

Figure 1 features temperature increases in the United States that are projected to occur between 2040-2059 based on a Representative Concentration Pathway (RCP) that assumes a greenhouse gas concentration of 4.5 based on radiative forcing. This RCP of 4.5 is considered somewhat conservative, but still probable. There are four RCP scenarios that are based on greenhouse gas concentrations (forcings of 2.6, 4.5, 6.0, and 8.5). If concentrations exceed 4.5, the situation will be even more dire. Given an assumption of concentrations of 4.5, the minimum temperature increase is projected to be as much as 3.0 degrees Celsius between 2040 and 2059.

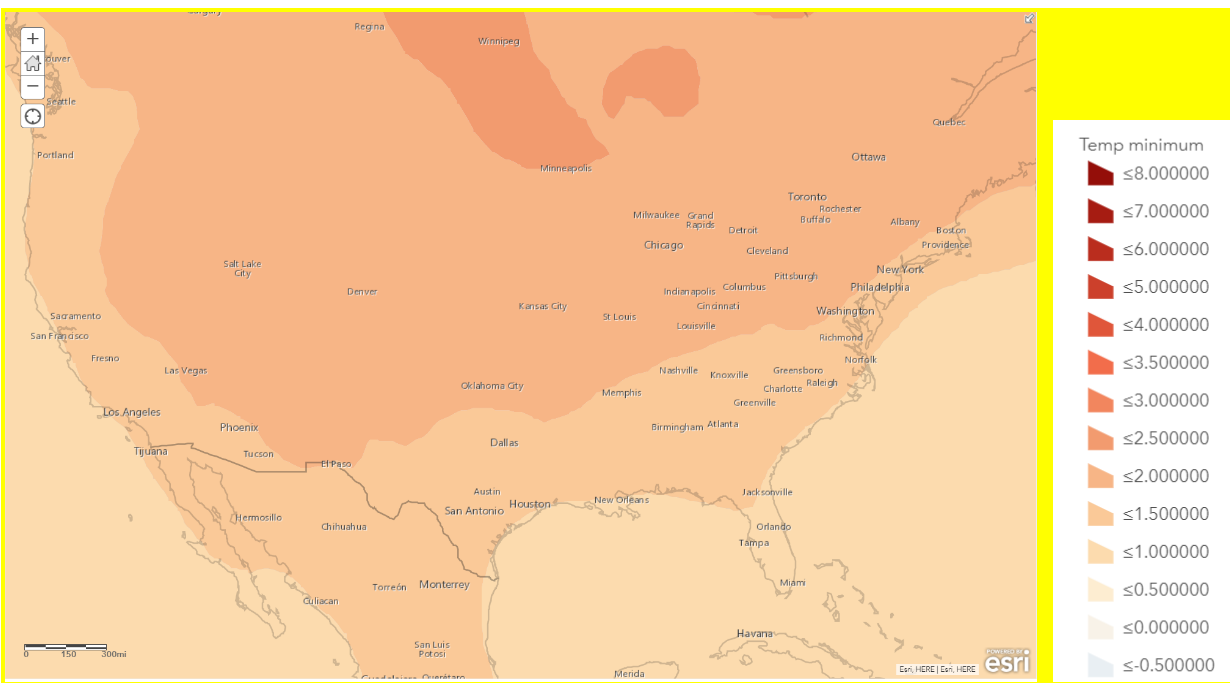

Figure 1. *Temperature Projections for the United States based on RCP of 4.5. Map created by Jeanette Shutay (2020). Map layers available from [ArcGIS Living Atlas of the World] (Esri, n.d.).*

In addition to temperature changes, changes in precipitation are also expected to occur. These changes in precipitation will create extreme circumstances where some areas that are already wet will experience even more precipitation resulting in flooding, and some areas that are dry will get even dryer resulting in droughts (Esri, 2019; Schmittner, 2018). Figure 2 depicts the current drought situation within the United States.

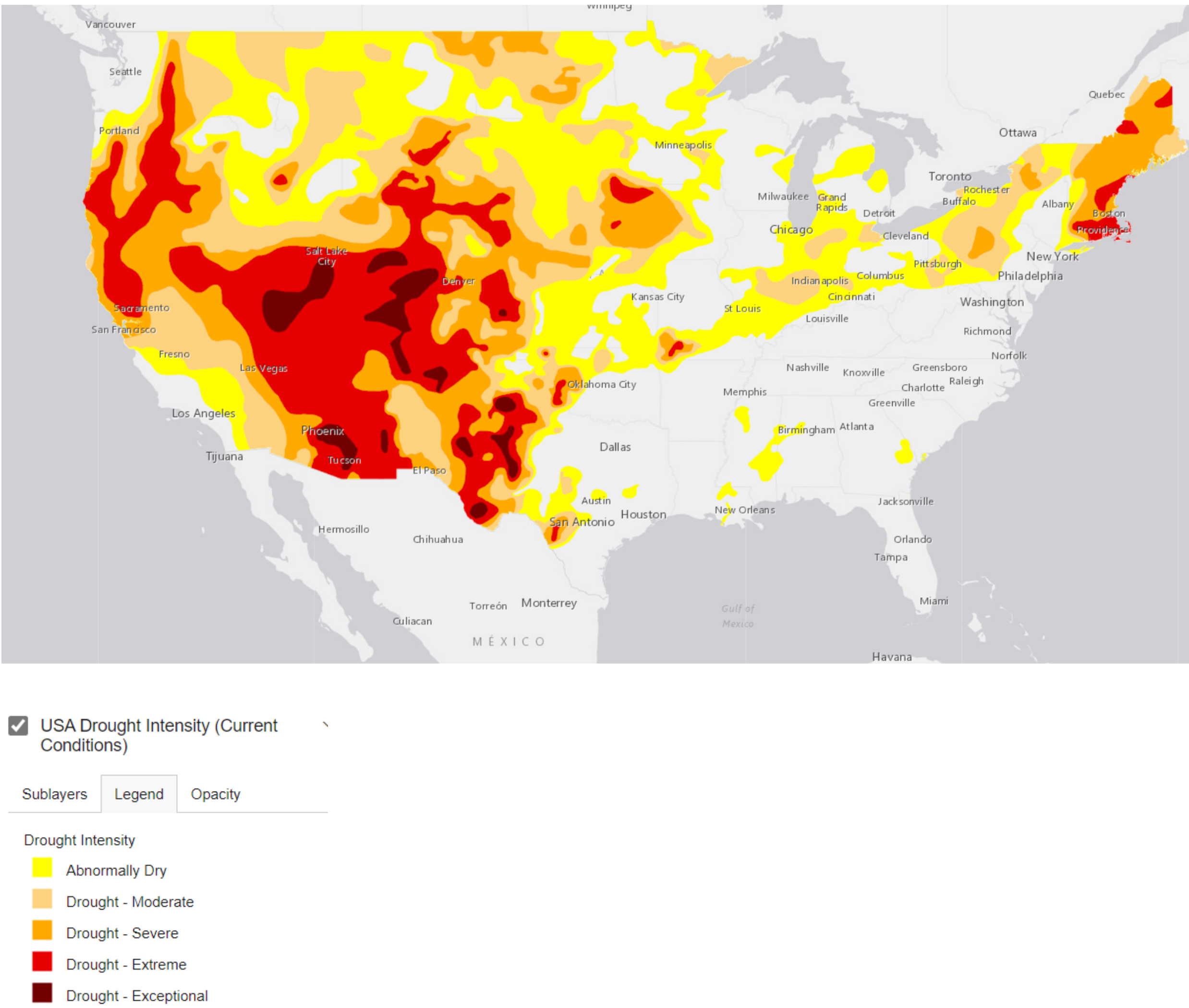

Figure 2. *Current Drought Intensity for the United States. Map created by Jeanette Shutay (2020). Map layers available from ArcGIS Living Atlas of the World (Esri, n.d.).*

These changes in temperature and precipitation will have significant impacts on the environment, putting $44 trillion of our economic value generation at risk given that businesses depend on nature and the ecosystem services that they provide (World Economic Forum, 2020). For example, climate change will have significant impacts on our food systems (Schmittner, 2018; Woetzel et al., 2020) by reducing agricultural production (Wienhold et al., 2018). When these systems are impacted, supply chains that procure and distribute food are impacted as well.

Climate Change and Food Systems

The relationship between climate change and our food systems is significant and complex. Climate change impacts not only weather-related factors, but it impacts biodiversity as well, which has knock-on effects impacting ecosystem services (Roberts et al., 2020). Specifically, disruptions to food production could be caused by extreme temperatures, droughts, and/or floods (Woetzel et al., 2020) creating a feedback loop where ecosystem services are degraded resulting in compounding effects (Wienhold et. al., 2018).

The Midwest region of the United States provides a case study demonstrating the relationship between climate change and disruptions to food systems (Yin et al., 2020). For example, severe flooding occurred in 2019 throughout the Midwest, which resulted in a growing season delay. The National Oceanic and Atmospheric Administration (NOAA) indicated that the measured 12-month precipitation hit a record high because of the extreme flooding that occurred in April through June. The record floods damaged local infrastructure and homes while also impacting agricultural yields.

As a result of delayed and reduced agricultural production, there was a reduction of 100 million metric tons of net carbon sequestration in the months of June and July (Yin et al. 2020). This example shows the existence of knock-on effects whereby climate change impacts flooding, which in turn impacts crop yields, which in turn impacts carbon sequestration. The reduction of carbon sequestration results in more carbon dioxide in the atmosphere further reinforcing climate change. Therefore, feedback loops exist and exacerbate the problem.

Given the severity of the issue, immediate efforts need to be taken to mitigate the potential damage, and simply reducing carbon emissions is not sufficient. According to the World Economic Forum (2020), a transition to productive and regenerative agriculture could provide substantial benefits to our food and land use systems. Specifically, farming and agricultural landscapes should be transformed by combining traditional farming practices, bio-based inputs, and advanced precision technologies to improve soil quality and water management, increase biodiversity, and enhance ecosystem services while simultaneously improving agricultural productivity.

Food Systems and Supply Chain Risks

It is natural to assume that food systems at risk have implications for supply chains and vice versa. For example, when a supply chain is disrupted by extreme weather events (e.g., hurricanes or typhoons), that disruption will have implications on the ability of the supply chain to distribute available food. Similarly, food systems that are disrupted by extreme weather events (e.g., droughts) will impact the supply chain's ability to meet consumer demand due to a lack of supply caused by a loss of agricultural productivity. In the first situation, there is sufficient supply of food but a disruption in the distribution mechanisms. In the second situation, there is insufficient supply to meet consumer demand. Not only does the lack of sufficient supply result in an inability to meet consumer demand, but it often results in supply chain shocks and instability.

A specific real-world example of disruptions to supply chain pertaining to volatility in demand and an unexpected drop in demand due to extreme weather events (Brusset & Bertrand,

2018) is the Polar Vortex that occurred in January 2019 in the Chicago region. Because of the extreme cold, many stores and restaurants closed for several days and many customers decided to stay in their homes. This type of situation not only resulted in food waste, but it created a situation where true demand was truncated because people were either not able to access the food (although there was a demand for it) or they were not willing to withstand the circumstances to access the food. When supply is based on historical demand, a demand signal indicating a false lack of demand can impact both upstream and downstream supply networks.

Supply chains are highly vulnerable to supply and demand shocks. When supply chains need to react to unanticipated demand or constrained supply, there are a number of ways that knock-on effects can come into play. For example, if there is insufficient supply due to underestimated demand, expedited deliveries are required, which will increase carbon emissions and costs to the system. Conversely, supplying more food than what is needed can result in food waste or reverse logistics (returning of product), where returning the excess demand increases carbon emissions and costs to the system.

COVID-19 provides an example of how shocks to the supply chain resulted in over and under supply based on changes in consumer demand and an inability to get the products produced or distributed to the consumers. While it is not currently known if COVID-19 is a zoonotic disease, one plausible hypothesis is that COVID-19 is a zoonotic disease that could have been facilitated by climate change (Bartlow et al., 2019; Mills et al., 2010). When things like zoonotic diseases occur (e.g., swine flu, bird flu, mad cow disease), they wreak havoc on our food systems and supply chains.

The supply chains of the future will need to be more resilient to dramatic system shocks based on climate-related factors. Focus will need to be placed on identifying and procuring demand signals that can inform predictive models by sensing and responding as proactively as possible. In a study conducted by Lim-Camacho et al. (2017), the authors concluded that more complex systems with a large number of nodes will be required for resiliency. However, all supply chains will experience diminished resiliency in the face of climate change and therefore more focus will need to be placed on diversified chains and broader systems approach, in combination with strategies for reducing greenhouse gas emissions (Lim-Camacho et al. 2017).

Conclusions

Anthropogenic climate change is posing a significant threat to our environment, including our food systems and supply chains (Schmittner, 2018; Woetzel et al., 2020). If immediate action is not taken, the average global temperature will likely increase by 4.1 degrees Celsius by 2100 (Roston & Murray, 2020). These climate changes will negatively impact biodiversity through forced extinctions (Roberts et al., 2020), degraded ecosystems, and lower quality ecosystem services (Wienhold et. al., 2018). The degradation of our ecosystems and ecosystem services will directly impact our food systems and supply chains.

One example of climate-related impacts to food systems include the record-high floods that occurred in the Midwest region in 2019, which caused delays in the growing season resulting in lower agricultural yields. Another example is the Polar Vortex that occurred in the Chicago region in January 2019, which caused store closures due to extreme cold weather. These store closures had the potential to result in false demand signals impacting the supply chain, as well as significant system waste and costs.

In addition to the direct problems associated with supply and demand complications, there are a number of ways that knock-on effects can come into play. For example, insufficient supply can result in expedited deliveries, which will increase carbon emissions and costs to the system. Conversely, an over supply results in food waste or reverse logistics (returning of product), increasing carbon emissions and costs to the system.

The supply chains of the future will need to be more resilient to dramatic system shocks based on climate-related factors. In addition to proactively identifying the most salient demand signals, more complex systems with a large number of nodes will be required for resiliency and more focus will need to be placed on diversified chains and a broader systems approach, in combination with strategies for reducing greenhouse gas emissions (Lim-Camacho et al. 2017). The ideal solution is to dramatically reduce carbon emissions in the future. However, even if that happens, historical emissions will impact global warming for the next few decades. Therefore, we must build resilient food systems and supply chains even in the most optimistic circumstances.

References

Bartlow, A. W., Manore, C., Xu, C., Kaufeld, K. A., Del Valle, S., Ziemann, A., Fairchild, G., & Fair, J. M. (2019). Forecasting Zoonotic Infectious Disease Response to Climate Change: Mosquito Vectors and a Changing Environment. Veterinary Sciences, 6(2). Retrieved from https://doi-org.proxy.lib.miamioh.edu/10.3390/vetsci6020040

Brusset, X., & Bertrand, J.-L. (2018). Hedging weather risk and coordinating supply chains. *Journal of Operations Management*, *64*, 41–52. Retrieved from https://journals-ohiolink-edu.proxy.lib.miamioh.edu/pg_200?::NO:200:P200_ARTICLEID:355531870

Esri (2019). *Terms, concepts, and common structures of climate data.* Retrieved from https://learn.arcgis.com/en/projects/explore-future-climate-projections/terms-concepts-and-common-structures-of-climate-data.htm

Esri (n.d.). ArcGIS living atlas of the world. Retrieved from https://livingatlas.arcgis.com/en/home/

Goulson, D. (2019). The insect apocalypse, and why it matters. Current Biology, 29(19), R967-R971. https://doi.org/10.1016/j.cub.2019.06.069

Lim-Camacho, L., Plagányi, É. E., Crimp, S., Hodgkinson, J. H., Hobday, A. J., Howden, S. M., & Loechel, B. (2017). Complex resource supply chains display higher resilience to simulated climate shocks. *Global Environmental Change Part A: Human & Policy Dimensions*, *46*, 126–138. Retrieved from https://journals-ohiolink-edu.proxy.lib.miamioh.edu/pg_200?::NO:200:P200_ARTICLEID:349368564

Mills, J. N., Gage, K. L., & Khan, A. S. (2010). Potential influence of climate change on vector-borne and zoonotic diseases: a review and proposed research plan. Environmental Health Perspectives, 118(11), 1507–1514. Retrieved from https://eds-b-ebscohost-com.proxy.lib.miamioh.edu/eds/pdfviewer/pdfviewer?vid=3&sid=a2171087-fd11-4c88-92a1-90e6300db9c2%40sessionmgr103

Prevedello, J. A., Winck, G. R., Weber, M. M., & Sinervo, N. E. (2019). Impacts of forestation and deforestation on local temperatures across the globe. *PLoS One 14*(3). Retrieved from https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0213368

Roberts, C. M., O'Leary, B. C., & Hawkins, J. P. (2020). Climate change mitigation and nature conservation both require higher protected area targets. *Philosophical Transactions Of The Royal Society Of London. Series B, Biological Sciences*, *375*(1794), 20190121. https://doi-org.proxy.lib.miamioh.edu/10.1098/rstb.2019.0121

Roston, E., & Murray, P. (2020, April 22). This Climate Simulator Lets You Decide How to Best Fight Global Warming. Retrieved from https://www.bloomberg.com/graphics/2020-global-warming-simulator/

Schmittner, A. (2018). Introduction to Climate Science. Oregon State University. Retrieved from https://open.oregonstate.education/climatechange/

Shutay, J. (2020, July 11). *Climate change: Causes and consequences.* Retrieved from https://storymaps.arcgis.com/stories/01d342cf9a52406ebe8e6803ef355cff

Wienhold, B., Derner, J., Hendrickson, J., & Vigil, M. (2018). Vulnerability of crops and croplands in the US Northern Plains to predicted climate change. *Climatic Change*, *146*(1–2), 219–230. Retrieved from https://eds-b-ebscohost-com.proxy.lib.miamioh.edu/eds/pdfviewer/pdfviewer?vid=21&sid=801e234e-390d-4265-a57e-2dafe9ce7195%40pdc-v-sessmgr01

Woetzel, J., Pinner, D., Samandari, H., Engel, H., Krishnan, M., Boland, B., & Powis, C. (2020). Climate risk and response: Physical hazards and socioeconomic impacts. *McKinsey Global Institute*. Retrieved from https://www.mckinsey.com/business-functions/sustainability/our-insights/climate-risk-and-response-physical-hazards-and-socioeconomic-impacts

World Economic Forum (2020). *The nature economy report II: The future of nature and business.* Retrieved from https://www.weforum.org/reports/new-nature-economy-report-ii-the-future-of-nature-and-business

Yin, Y., Byrne, B., Liu, J., Wennberg, P.O., Davis, K.J., Magney, T., Kohler, P., & He, L., (2020). Cropland carbon uptake delayed and reduced by 2019 Midwest floods. AGU Advances, 1, e2019AV000140. https://doi.org/10.1029/2019AV000140.