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The attached educational project, by ALEXANDER DENZ, entitled THE IMPACTS OF GLOBAL WARMING ON U.S. SUPPLY CHAINS, when completed, is to be submitted to the Graduate Faculty of the University of Wisconsin- Platteville in partial fulfillment of the requirements for the (MASTER OF SCIENCE IN INTEGRATED SUPPLY CHAIN MANAGEMENT) degree.

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MASTER OF SCIENCE IN INTEGRATED SUPPLY CHAIN MANAGEMENT

By

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Abstract

Global warming is expected to change our climate, increase the likelihood and severity of life-changing weather events, and may make certain parts of our world uninhabitable. In response to these expected events, governments may pass increased legislation to help reduce the output of fossil fuels and consumers may alter their buying habits to place increased value on sustainable products and businesses. These changes will create a changing landscape for supply chains that will impact procurement strategies, facility footprint planning, distribution strategies, and will potentially create opportunities in developing markets as consumers align their purchases with the goal of creating a more sustainable planet. How companies respond to these changes will separate them from competitors in the 21st century and beyond. This study will provide guidance to supply chain leaders in building a resilient, sustainable, and profit-enhancing supply chain.

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Introduction

"Climate change is impacting production costs, reducing delivery speed and affecting the quality of goods delivered to the end-user. Unpredictable natural disasters arising due to climate change are increasing the fragility of the supply chain industry." (Explained: How Climate Change Impacts the Shipping and Supply Chain Industry, 2021) The existence of climate change, as a result of human-induced activity, has become a majority position of thought over the course of the last twenty years. "CO2 emissions boost global warming, causing ocean temperatures to rise. When temperatures rise, warm waters cause intense hurricanes that disrupt the supply chain industry and derange global commerce trade." (Explained: How Climate Change Impacts the Shipping and Supply Chain Industry, 2021) The negative outcomes expected from global warming include more frequent severe weather events, ocean sea-level rise causing population migrations and damage to existing infrastructure, and increased focus and legislation designed to reduce CO2 emissions. Supply chain leaders need to prepare their supply chains for a future where global warming impacts increase and add incremental risk to their organizations.

This paper will focus on specific actions and strategies that supply chain leaders should take in procurement, distribution, and planning. Taking these steps will enable competitive cost structures, agile supply, reduced risk in the supply chain, and the ability to gain market share as a result of other firms not taking the same risk mitigation steps in their climate change preparation plan.

Firms need to fully review their supplier base to identify risks, understand their supplier's focus on sustainability and green initiatives, and understand what alternatives exist to meet your organization's needs. Many firms are beginning to see their supply source threatened or reduced as a result of climate change and are being forced into reviewing alternative products and sources

to substitute existing supply sources. “Wildfires in the American West, flooding in China and Europe, and drought in South America are already disrupting supplies of everything from lumber to chocolate to sushi rice.” (Olick, 2021) This phenomenon is causing reduced supply, increased costs, and future unpredictability. Supply chain leaders need to respond by adding backup and supplementary suppliers, increasing supplier scorecard weights for sustainability, increasing communication with suppliers to gain visibility to future stock-outs, and reviewing product substitutes that are more resilient and sustainable in this business climate. Firms learned many of these lessons in the most recent supply chain issues associated with COVID-19 and they are only expected to amplify with the impacts of climate change as these have the potential to be long-term shifts as opposed to short-term occurrences. “The wildfires burning in Western Canada are significantly impacting the supply chain and our ability to transport product to market, Canadian lumber producer Canfor Corp. said in July. As a result, we are implementing short-term production curtailments at our Canadian sawmills.” (Olick, 2021) This specific example shows the importance of staying current with global warming related supply chain impacts. Firms that directly buy lumper will certainly understand and respond to these changes, but downstream impacts need to be calculated. In this example, manufacturers of nails, screws, washers, refrigerators, etc. need to be aware of these impacts because increased lumber prices may result in an increase in housing costs, which could lead to reduced homes being built and reduced demand for their associated products.

Distribution risk mitigation involves near-shoring and on-shoring, identifying key nodes in the supply chain with heightened risk, holding extra inventory, reducing your firm’s carbon footprint, and building response plans for severe weather events. “The supply chain and shipping industry contributes to a staggering 80% of the global greenhouse gas emissions causing climate

change." (Explained: How Climate Change Impacts the Shipping and Supply Chain Industry, 2021) The need to ship large quantities of goods is a main driver of climate change and thus creates a complex decision point for firms. Firms have leveraged off-shoring and international shipping to stay cost-competitive from the 20th century to the present. However, as the need to reduce fossil fuels amplifies, these firms may need to consider near-shoring and on-shoring because the costs, environmental impact, and risk of off-shoring a large percentage of their supply may become too great. In addition to moving operations closer to consumers, assembly, and other downstream activities, firms should improve their own carbon footprint through initiatives in intermodal shipping, utilizing electric vehicles, selecting carbon-neutral warehouses, and engineering sustainable packaging. Firms need to be mindful of the key distribution nodes in their supply chain. If a firm has key distribution nodes in areas that are prone to negative impacts of rising sea levels and natural disasters then they may opt to move these nodes or minimize the assets that are kept at these nodes to mitigate product loss risk.

Supply chain planning organizations will need to think about their supply strategy differently than the lean principles that were adopted and perfected at the end of the 20th century and the beginning of the 21st century. "For example, Toyota used to rely almost entirely on a lean manufacturing model, sourcing critical parts at the last minute. This is a model that no longer works." (Leise, 2021) Successful supply chains now need to hold additional supply and be strategic about where that extra supply is stored. "Top strategies to mitigate supply-chain risk are often referred to as bridging and buffering. Bridging means bridging the gap with suppliers to make sure communication is strong during a climate crisis. Buffering means having some products in reserve as a buffer and having backup suppliers should the main ones fail." (Olick, 2021) Firms will need to be closer to their supplier's supply risks than ever before, to include a

firm's supplier's suppliers, to a greater extent than in the past. Firms need to be a step ahead of their competition in understanding supply risks so they can investigate alternatives and communicate impacts to their firms before they happen.

Firms that successfully deploy climate change risk mitigation actions and strategies will have the upper hand in the future. They will be able to keep their shelves stocked, assets at increased up-time, customers happy, and their costs low. There will likely be firms that don't apply the same strategies and they will not be as successful in the future. As a result, there will be an increased opportunity in the marketplace and successful supply chain leaders will need to continue to focus on growth with key suppliers. In addition to advantages from a supply and cost perspective, firms that are able to showcase their sustainability initiatives will have increased consumer demand because more consumers will want to align themselves with companies that promote the sustainability of our planet.

Literature Review

"Could climate become the weak link in your supply chain?"

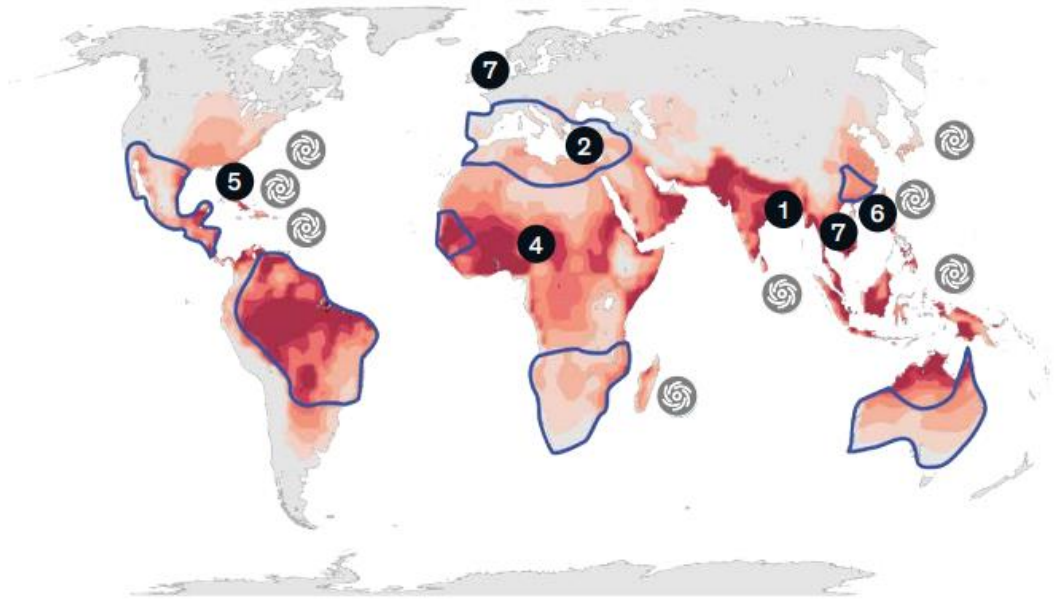
The McKinsey Global Institute presented a general overview of supply chain risks, potential outcomes, and opportunities for supply chain leaders. Their research discusses global impacts of weather, varying levels of risk based on the supply's availability and sourcing diversity, and shares case studies of downstream impacts of semiconductor and rare earth supply variability. In response to these reviews, they recommend five areas of action to focus on to reduce the impacts of global warming on the supply chain.

In 2011, Thailand was impacted by severe flooding. "Flooding lasted 30 to 60 days, disrupted global electronics, automotive and food supply chains, and resulted in losses totaling $40 billion to $50 billion." (McKinsey Global Institute, 2020) The industrial sector of Thailand was highly concentrated in a high-risk flooding area and the flood management infrastructure wasn't strong enough to prevent the damage and enable quick recovery. "The electronics and automotive industries were hardest hit and experienced an 80 percent year-on-year decline in production in November" (McKinsey Global Institute, 2020) Prices soared on electronic components, downstream production needed to be curtailed due to lack of supply, and the end consumer saw increased stock-outs and higher prices.

Figure 1 provides leaders with a global view of projected heat impacts by 2050, areas with a higher probability of natural disasters, and a few case studies to evaluate if your firm is exposed to global climate change risks. Each part of the globe has unique challenges associated with climate change that range from livability, food availability, infrastructure resilience, and physical assets.

Figure 1

Nine case studies of leading-edge climate change impacts across all major geographies, sectors, and affected systems.



Livability and workability	1	Will India get too hot to work?
	2	A Mediterranean basin without a Mediterranean climate?
Food systems	3	Will the world's breadbaskets become less reliable?
	4	How will African farmers adjust to changing patterns of precipitation?
Physical assets	5	Will mortgages and markets stay afloat in Florida?
	6	Could climate become the weak link in your supply chain?
Infrastructure services	7	Can coastal cities turn the tide on rising flood risk?
	8	Will infrastructure bend or break under climate stress?
Natural capital	9	Reduced dividends on natural capital?

1. Heat stress measured in wet-bulb temperatures.
2. Drought risk defined based on time in drought according to Palmer Drought Severity index (PDSI).
Source: Woods Hole Research Center; McKinsey Global Institute analysis

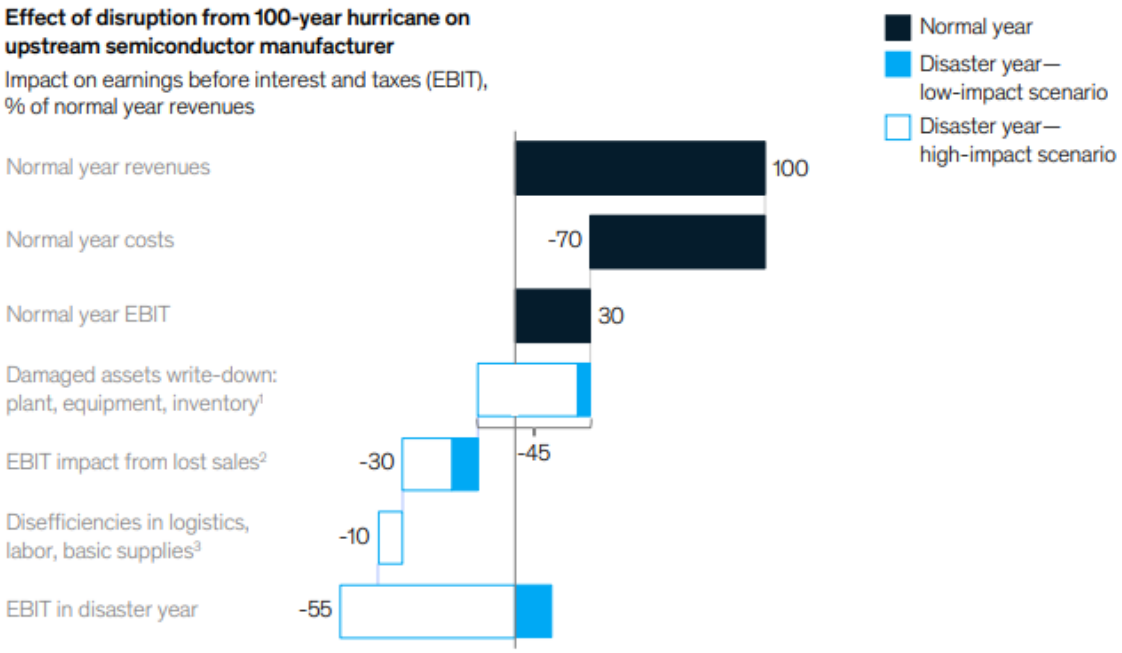
Note – From "Could Climate Become the Weak Link in Your Supply Chain?" *McKinsey Global Institute*, McKinsey Global Institute, Aug. 2020

Lean and just-in-time principles have been a key focus of supply chains since the 20th century. Firms carefully managed their inventory to reduce working capital costs and enabled them to spend their cash in other areas to enable growth. The COVID-19 pandemic showed the value in holding additional inventory to prepare for external risks in the supply chain. These same principles apply and need to be reviewed in preparing for the impacts of global warming. Firms need to have diversified supply in terms of locations, supplier portfolio, and potential alternatives. However, many firms are not prepared, or don't have access to meet this expectation. "For example, in a 2018 survey, 88 percent of suppliers across industries responded that they have only one production site available for each of their products. This was especially true in aerospace and defense and pharmaceuticals, where high safety requirements and long lead times to acquire regulatory approval increase the cost of new manufacturing facilities." (McKinsey Global Institute, 2020)

The text categorizes suppliers into three categories – Specialty, Intermediate, and Commodity. Specialty suppliers provide a unique offering to the market with little competition. These agreements are strategic in nature and are often accompanied by long-term contracts. Commodity suppliers involve transactions that aren't between a supplier and buyer. There is an intermediate broker and there is little to no variability in product quality from different suppliers. Intermediate suppliers are a mix between Specialty and Commodity suppliers. There are multiple suppliers in the sector and buyers can switch between suppliers. There are contracts, but they're generally shorter in nature and less strategic than contracts for Specialty suppliers. The text

highlights these differences so firms can categorize their supplier base and assess their risk. Specialty suppliers are most susceptible to the impacts of global warming as the source of supply may come from a limited area and the buyer has limited options in the open market. It's key for buyers to mitigate risk for Specialty suppliers through supplier development and leverage Intermediate and Commodity suppliers through favorable inventory management programs, contractual mechanisms, and reducing risk through multiple suppliers.

Figure 2



Note – From "Could Climate Become the Weak Link in Your Supply Chain?" *McKinsey Global Institute*, McKinsey Global Institute, Aug. 2020

Figure 2 highlights how natural disasters can impact a buyer if their upstream supplier is impacted by downtime and loss. Firms that are prepared can mitigate their losses. The text recommends five strategic areas for leaders to consider – "protecting supply chain assets, redesigning supply chain operations, reducing exposure by creating alternatives, allocating risk

by using financial and contractual mechanisms, and shoring up supply chain infrastructure" (McKinsey Global Institute, 2020)

One example of protecting supply chain assets is disaster proofing plants and key distribution sites. "We find that building disaster-proof plants means additional costs of roughly 2 percent of the building costs which equals an additional $20 million for an average plant." (McKinsey Global Institute, 2020) These financial exercises can help leaders understand their ROI and cost versus benefits for investments in their supply chain.

Redesigning supply chain operations and reducing exposure are complimentary tasks for the supply chain. Re-evaluating WIP and finished goods levels to accommodate different risks scenarios and ensuring stability of lead time throughout the supply chain during disruptions are key tasks in this effort. Sourcing and marketing will need to collaborate to build direct alternatives and substitutes so the supply chain can be flexible through disturbances.

"Modelling the impact of climate change risk on supply chain performance"

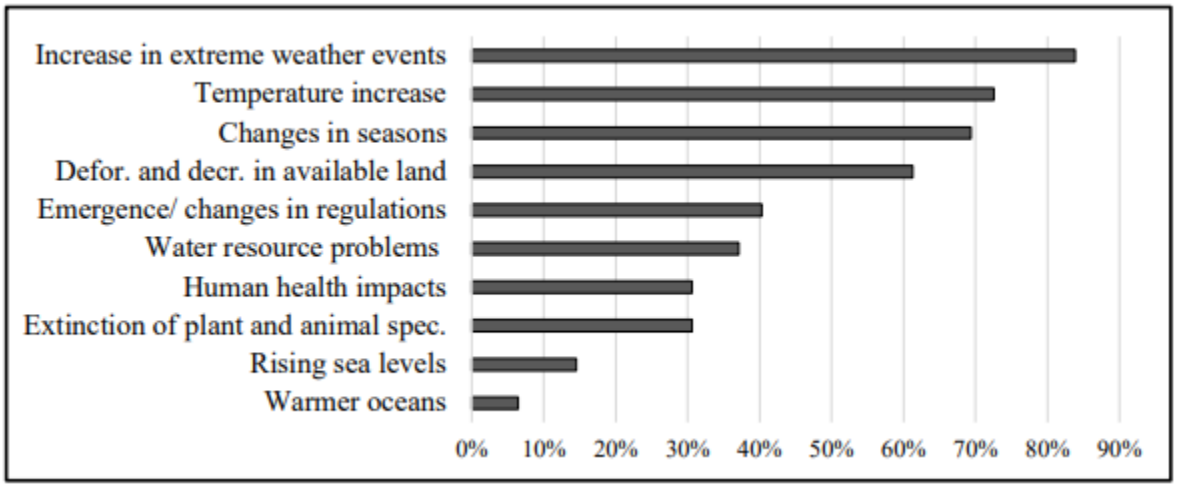
The text aims to quantify the impacts that global climate change will have on supply chains. The method for delivering this model involved surveying supply chain leaders to understand their level of preparedness and areas of greatest concern. The most common threats and considerations were mapped out along with key financial and strategic measures of success. The research team built a cognitive map to connect these nodes and modeled out various scenarios to project future supply chain effectiveness and efficiency.

Figures 3 and 4 illustrate the survey results from industry leaders indicating how they think climate change will impact daily life and their business. The model connects the supply chain functions listed by industry leaders to events such as wildfires, water shortages, heatwaves, hurricanes, energy availability, etc. and quantifies the impacts to key metrics in the supply chain.

These metrics include customer satisfaction, raw material prices, increased inventory, working capital levels, delivery lead time, and more. These metrics are then categorized into supply chain effectiveness and efficiency and are weighted to align with frequency and impact.

Figure 3

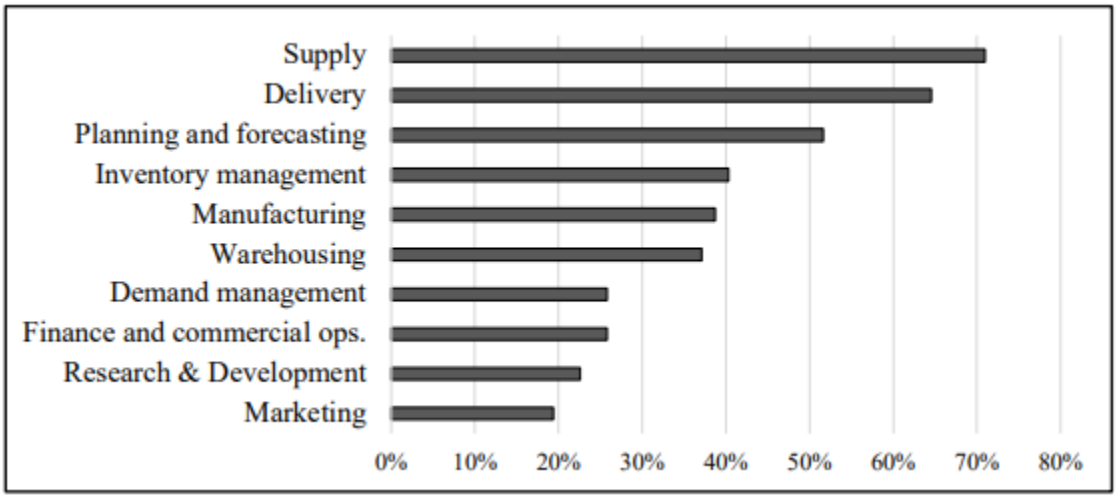
Response for most influential climate change factors



Note – From "Modelling the Impact of Climate Change Risk on Supply Chain Performance." July 2020

Figure 4

Response for most impacted SC functions due to climate change



Note – From "Modelling the Impact of Climate Change Risk on Supply Chain Performance." July 2020

The output of the model includes nine different scenarios, shown in Figure 5, that allow for independent variation in the degradation in performance of availability of raw materials and logistics operations. The variability may occur based on model accuracy, the firm taking action to mitigate these impacts, or human behavior curbs or accelerates climate change impact. By providing variability between these two factors, firms can see where they have the greatest ROI and risk when considering proactive actions.

Figure 5

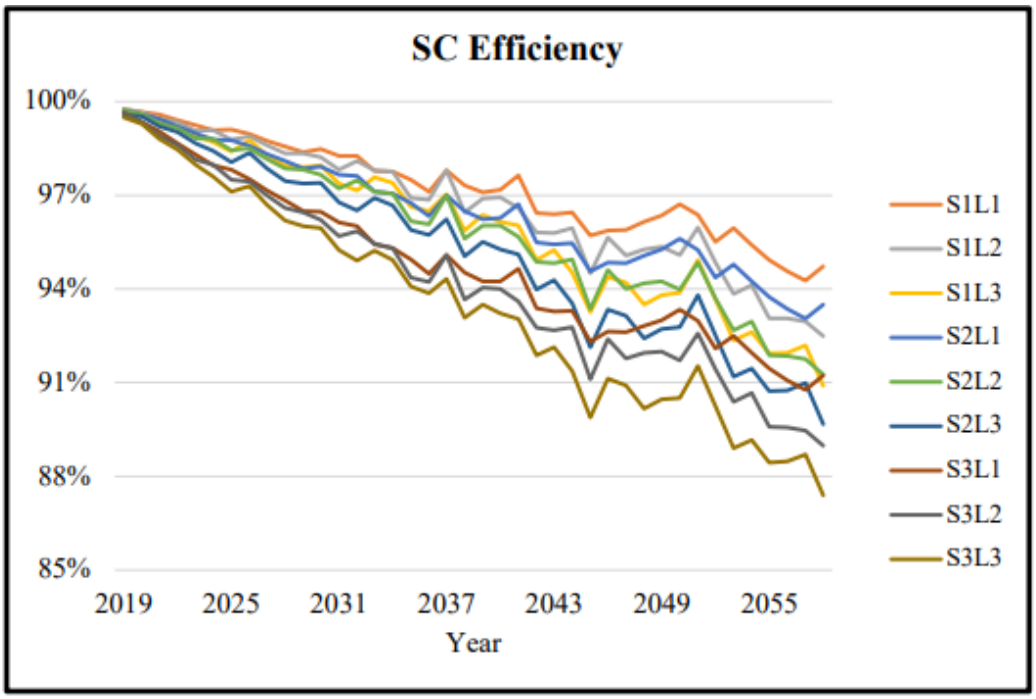
Summary of Scenarios

Scenarios	Effect of climate change on the supply chain					
	Availability of raw materials			Logistics operations		
	Low	Moderate	High	Low	Moderate	High
S1L1	✓			✓		
S1L2	✓				✓	
S1L3	✓					✓
S2L1		✓		✓		
S2L2		✓			✓	
S2L3		✓				✓
S3L1			✓	✓		
S3L2			✓		✓	
S3L3			✓			✓

Note – From "Modelling the Impact of Climate Change Risk on Supply …" July 2020

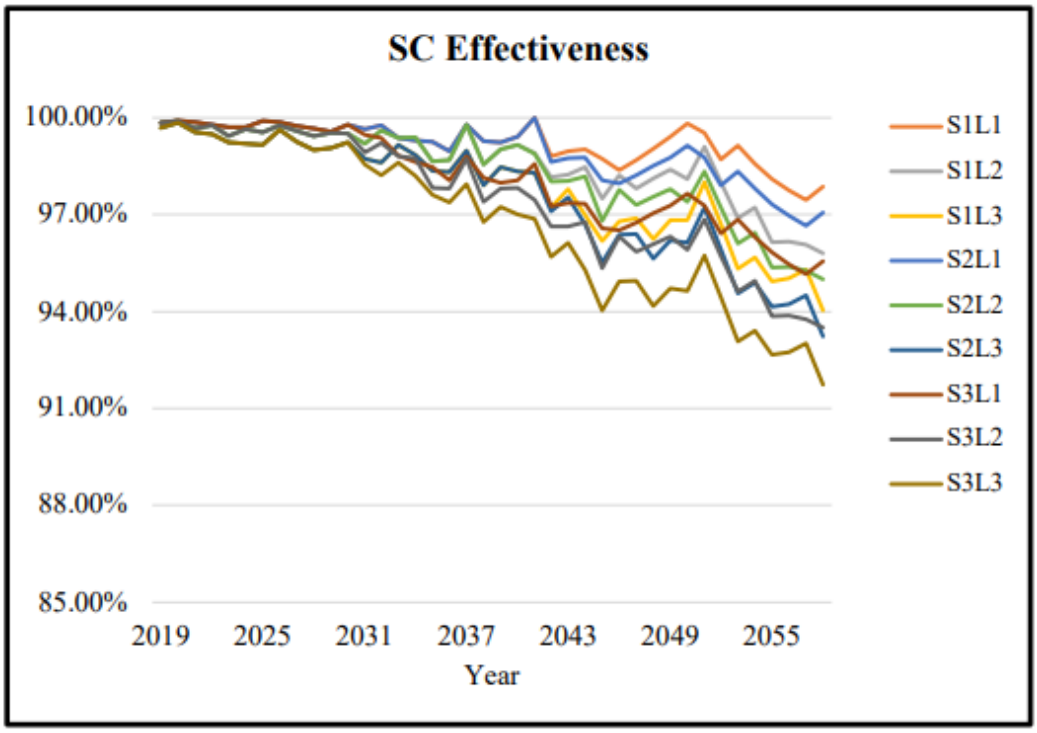
The output of the model is shown in Figures 6 and 7. “SC efficiency was defined as a change function of unit cost and manufacturing productivity. SC effectiveness was calculated by stockout amount, deviation in lead time and delays in delivery” (Er, 2020) The model output includes visibility to the direct inputs into effectiveness and efficiency so they can customize their approach to their greatest area of need and positive return. For example, the text shows the future, non-linear projection of raw material prices and availability so firms can plan from a marketing and sourcing perspective.

Figure 6



Note – From “Modelling the Impact of Climate Change Risk on Supply Chain Performance.” July 2020

Figure 7



Note – From "Modelling the Impact of Climate Change Risk on Supply Chain Performance." July 2020

The text concludes that supply chains will be impacted by climate change with a high degree of certainty. Additionally, the model shows that firms and humans can take action to mitigate the impacts of climate change to improve supply chain effectiveness and maintain a more consistent quality of life. The researchers noted variability in the level of preparedness of supply chain leaders included in their survey and found that many surveyed noted that climate change risk was an under-valued aspect of the firm's strategy and areas of opportunity. Firms can use these results to prioritize and quantify their risk mitigation efforts so they can be successful in the future.

“Supply chain management in view of climate change: An overview of possible impacts and the road ahead”

This article provides a summary of supply chain impacts, implications for supply chains, and provides guidance on how firms can proactively address these supply chain opportunities. Figure 8 shows the categorization and specific considerations associated with each specific supply chain function. These issues are discussed in greater detail with associated opportunities for supply chain leaders to consider in risk mitigation, cost reduction, and improved customer service.

Figure 8

Climate change impacts to supply chain links

Supply chain links	Typology of climate change impacts/risks
Manufacturing	• damage or complete destruction of assets • liability risks • disruption of plants and production lines • regulation with regard to carbon emissions • changes in the effectiveness or efficiency of production processes • increased costs for energy and maintenance activities • increased cost of upstream operations and product quality • stimulation of investments in renewable energy and energy efficiency projects increase in demand for biofuels and renewable energy sources in the energy sector • increase in demand for pharmaceuticals’ sector • stimulation of demand for non-emitting products • deployment of lower carbon intensity operating practices by market leaders development of diversified products based on lower GHG emissions
Transportation	• increase in buckled rails and rutted roads • delays leading to paying compensation to operators and causing problems to customers • overhead cables brought down because of strong winds • problems related to coastal defences • drainage issues • landslip resulting from heavy rainfall • securing stability of structures
Warehousing and storage	• vulnerability of infrastructure, personnel, communications, supply etc • possible dislocation due to extreme weather events
Trading	• reputational risk in downstream sectors due to increased need for transparency • new regulations regarding product labeling • increases in the consumer goods production costs and prices • decrease of demand for consumer products
Consumption and Customer Service	• need for improved product design aiming at the elimination of packaging material and the enhancement of product durability, reusability, recyclability, and materials efficiency

Note – From "Supply Chain Management in View of Climate Change: An Overview of Possible Impacts and the Road Ahead." Sept. 2013

The article focuses on the role of technology in addressing some of these supply chain concerns. "In the case, for example, of freight transportation, ICT may increase capacity utilization and, therefore, lead to reductions in energy usage" (Dasaklis, Thomas K, and Costas P Pappis, 2013) Firms can also leverage technology to improve their inventory turnover by improved forecasting, automated and optimized inventory decisions, and warehousing activity optimization. Many firms still use manual processes, with inherent variability, across the supply chain industry. By improving the technology and supply chain efficiency, firms can create less waste and use less energy to produce and ship products.

Supply chains, and specifically transportation activities, are significant contributors to global climate change. By utilizing intermodal instead of truckload, working with carriers that utilize low or no emissions vehicles, and utilizing warehouses that have a minimal carbon footprint are key activities to promote supply chain sustainability. Firms can leverage technology to increase their lead times using intermodal transit and carry the correct amount of inventory. Some carriers are already implementing electric trucks and improving their own carbon footprint. By choosing carriers that promote green initiatives, the firm is positively contributed to reducing climate change and they can use this information to promote their brand and educate consumers.

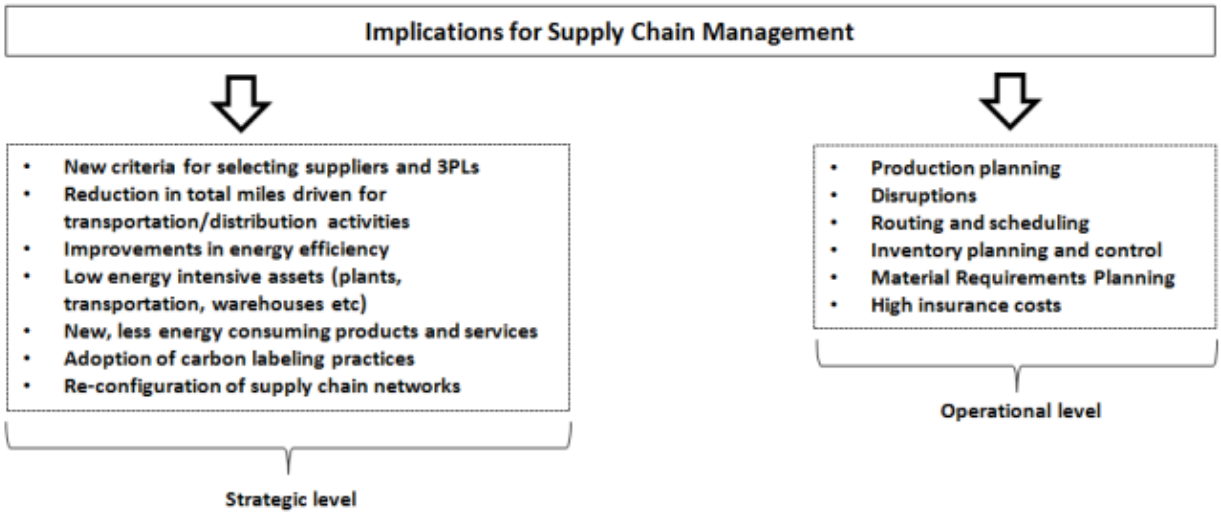
The supply chain impacts from global warming will likely impact all levels of the organization; from marketing, to finance, and operations. Firms have a responsibility to decrease their own carbon footprint and the carbon footprint of their whole supply chain. The results of each firm's sustainability performance will become more transparent as the negative outcomes of

global warming become more intense and apparent. This will create an opportunity to create a competitive advantage by offering new products and giving consumer's confidence that their purchases aren't negatively contributing to global warming.

Firms will need to build more nimble organizations and leverage technology, inventory, insurance, and contingency plans. By building contingency plans, firms can optimize their inventory and strategically locate their inventory to be more resilient to natural disasters and disruptions. It's critical that cross-functional groups are aware of this shift so they can take appropriate actions in pricing, product development, and budgeting. Additionally, elevated insurance may be necessary to protect the firm.

Figure 9

Implications of climate change drivers for SCM



Note – From "Supply Chain Management in View of Climate Change: An Overview of Possible Impacts and the Road Ahead." Sept. 2013

Firms have a growing support system of resources to begin building improved processes and infrastructure. Local and national agencies, as well as local businesses, are all gaining awareness of this issue and are building teams to improve their carbon footprint.

Organizations should become aware and involved in these efforts and collaboration to learn and share best practices. Firms also need to look at traditional problems differently. Climate risk needs to add considerations in technology investments, transportation strategy, and asset improvement. The payback calculation needs to be inclusive of brand considerations and elevated future risk to an extent that hasn't traditionally been explored.

Methodology

The goal of my paper is to show the supply chain problems associated with global warming, share tactical and strategic considerations for supply chain leaders, share ways that organizations can reduce their own carbon footprint, and share potential outcomes associated with taking a proactive, strategic approach to sourcing and distribution in a global warming conscience environment. The introduction of this paper highlights this scope and focuses on the problem at hand. The literature review and discussion will provide the future roadmap for making improvements that are positive for their organization's bottom line and the planet.

I am utilizing scholarly articles from business groups and members of academia for my sources in the literature review and the discussion. My 11 years of supply chain experience and my previous coursework have guided my literature investigation. I specifically targeted articles that provided general guidance for supply chain leaders related to global warming, articles with case studies, articles that discussed the benefits of switching to more environmentally friendly internal practices such as facility improvement, intermodal conversation, and on-shoring, and articles that modeled the impacts of global warming on supply chain activities. I was able to utilize these articles to show a clear progression through the paper from the problem, to general considerations, to solutions, and a data-driven model to highlight outcomes.

This paper is very general and broad in its scope. The intent is to provide a comprehensive review and a few considerations to take back to the reader's own organizations and research their specific opportunities in greater detail. The broad scope of this paper also illustrates that most organizations will be impacted by the impacts of global warming and should take action in some way. The limitations of the paper, and the research, is that it isn't detailed enough to provide a clear blueprint for an organization's specific opportunities.

Discussion and Conclusions

"Climate change can upend supply chains in obvious ways — sudden floods, flash fires - as well as through secondary repercussions like a migrating workforce or infrastructure in need of a retrofit. And those scenarios and others stand to directly affect a company's bottom line." (Baskin, 2020) In order for firms to be competitive in this dynamic supply chain landscape, they need to take action in their distribution strategy, procurement focus, inventory parameters, and they need to be stewards of the environment in their own operation. This paper aims at providing considerations and pathways to internal sustainability and risk mitigation.

Developing suppliers with a focus on sustainability, creating supply substitutes, and increasing supplier communication is key to limiting supply disruptions as global warming impacts continue. The McKinley text highlights case studies showing the impacts of shortages of key products and things those buyers learned through the process. Purchasing leaders need to put a higher weight on sustainability in purchasing decisions and on the supplier scorecard. Creating partnerships with suppliers that are conscious of their environmental impact will gain increased importance from a marketing and compliance perspective. By developing substitute supply chains, firms can be prepared if their main supply arm is impacted by a catastrophic disaster.

"Classic inventory models cannot monitor emerging issues in the industrial sectors such as managing inventory overage, product marketing, growing consumer consumption, inefficient manufacturing processes, GHG emissions related to inventory management, and logistics and transportation operations. Inventory planning and management should be analyzed from a financial, environmental, and social perspective to solve these concerns" (Pattnaik, 2021) Firms need to look at inventory management differently than they have in the past, as recently

evidenced by the supply chain impacts of the COVID-19 pandemic. There is increased supply risk as a result of global warming due to drought, famine, increased severe natural disasters, forest fires, etc. In some instances, firms need to hold additional inventory than traditional models would indicate to buffer against the impacts of some of these unforeseen impacts that can lead to increased lead time for future orders. In other cases, firms need to be leaner in their inventory management to be better stewards of the environment.

Firms need to take increased responsibility for their own carbon footprint. This includes the energy provided to facilities owned by the firm, the modes of transportation used by providers, and the chemicals used by their suppliers. Consumers will have an increased desire to purchase green products and governments will increase legislation forcing companies to produce items that are environmentally responsible. Firms can increase their use of intermodal, utilize carriers that have electric trucks, and utilize renewable energy for their facilities.

Recommendations and Implications

This is a general view of the impacts that global warming will have on U.S. supply chains. Firms can use this paper to understand the impetus of implementing global warming conscious parameters into their supply chain and begin to develop an understanding of where to look for improvements. Firms will need to take a more detailed look into their specific issues and this paper is designed to provide at least one consideration for each U.S. supply chain.

Supply chains are a major contributor to adding greenhouse gas emissions to our plant. By taking steps to develop more green supply chains, firms can reduce the business impacts of

global warming and increase the sustainability of our planet. Firms can also market their focus on reducing greenhouse emissions to increase market share.

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