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Impacts of Climate Change on Logistics and Supply Chains

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Abstract

While the global public is struggling with Covid-19 and the subsequent inflation, war and energy crisis, climate change has turned into a forgotten crisis. However, with the increasing number of disasters caused by extreme weather events in different continents of the world, climate change has started to attract attention all over the world. Extreme weather events such as global warming, floods and hurricanes, which are the result of global climate change, not only affect the lives of societies, but also affect logistics and supply chains. The first spots to see the effects of extreme weather conditions as a result of climate change are the production centers in different parts of the world and the international logistics sector, which ensures that the goods produced in these facilities reach the markets. By this study, the qualitative effects of climate change on supply chains were investigated and this research is expected to shed light on the effects of climate change on international logistics activities.

Keywords: Climate Change, Global Warming, Logistics, Supply Chain

1. INTRODUCTION

Climate change, which is felt more and more each year, has been overshadowed by the coronavirus pandemic, which emerged in China in the last days of 2019 and damaged the global economy much more severely than the global financial crisis that broke out in 2008 (Gopinath, 2020; URL 1). While the governments were struggling with the global health crisis, which was caught unprepared, global warming turned into a forgotten crisis. However, towards the end of 2021, with the decrease of the effects of the global pandemic, the issue of climate change has started to attract attention again. In a study conducted in Germany in which respondents were asked to select the two most important issues among the twelve issues facing the country, from social policy to the economy, climate change was at the top of the list by 43% of the respondents, followed by coronavirus with 38% (URL 2). The effects of the pandemic have eased, but this time, climate change continues to be overshadowed due to global inflation, war and energy crisis. Undoubtedly, the increase in air temperatures in recent years has a large share in the increasing interest of societies against climate change. Because the last eight years have been the warmest years since the 1800s, when global temperature records were started to be kept, and even 2021 has been recorded as the fifth warmest year (URL 3).

Bigger, more complex and more uncertain than other environmental problems, climate change is affecting agriculture, energy use, health and many aspects of nature, which means it affects everything and everyone. The causes and consequences of climate change are very diverse (Tol,

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2009). Rising temperatures, persistent multi-year and severe droughts, storms, rising sea levels, melting glaciers and warming oceans in connection with climate change affect human activities and bottleneck global supply chains, which is the focus of this study. The globalized production system, characterized by low transportation costs, economies of scale and comparative advantages, has increased the links between producers and consumers all over the world (Andreoni and Miola, 2015). Floods, hurricanes, high temperatures and forest fires that have emerged in different parts of the world in recent years affect one link of global supply chains, and this effect carries the risk of spreading to the entire network. Supply chains have a vital role in the development of global economies. Evaluating the economic consequences of disruptions in the regular flow of goods and services of global climate change is becoming more and more important for macroeconomic analyzes and economic policies. In this context, various central banks have begun to assess the consequences of climate change on the conduct of monetary policy, recognizing that supply shocks related to, for example, extreme weather events can strike a balance between stable inflation or output (Cœuré, 2018).

On the other hand, activities such as production, transportation, storage and distribution carried out in supply chains have serious effects on climate change.

The remainder of this article is organized as follows. In Chapter 3, climate change is examined in general terms. In Chapter 4, the effects of climate change on the supply chains and the effects on the main activity areas of the supply chain are investigated. The study was based on existing secondary sources, including books, regional and international reports, scientific journals, news articles and internet resources highlighting climate change-related supply chain issues, and expert interview.

In this study, the qualitative effects of climate change on supply chains were investigated and this research is expected to shed light on the effects of climate in international logistics activities.

2. LITERATURE REVIEW

Climate change has been a recognized issue throughout history, but as a science, theory and evidence have been studied for the last two centuries. In the 1820s, French physicist and mathematician Joseph Fourier, realizing that the atmosphere traps heat, studied the heat balance equations for the Earth. He concluded that the planet was about 30°C hotter than these equations suggest, arguing that something was blocking the energy output (Stern, 2015).

In recent years, climate change has become one of the most important challenges at practically all levels of decision-making, both governmental and private. Climate change, which is a result of global warming, is a universal reality that affects the life of human societies, business activities and the environment itself in many ways (Stern et al., 2010). The mid-1990s work of William Nordhaus on an integrated quantitative assessment model to explain the relationship between the economy and climate earned him the 2018 Nobel Prize in Economics (URL 4). Academic studies in the context of supply chains and climate change have been evaluated from many different perspectives. These studies can be divided into two groups as the effects of supply chain activities on climate change and the effects of climate change on supply chain activities. In the context of the effects of supply chain activities on climate change, Solaymani (2019) examined the CO2 emission models and the transportation sector in the seven economies that emit the most carbon in his study. Zhang et al. (2018) investigated the analysis of an optimal mass transit structure under carbon emission constraint on a case in China. Wan and his team (2018)

presented solutions and policy recommendations regarding the decarbonization of the international shipping industry.

The effects of climate change, which is also the subject of this research, on supply chain activities have started to attract the attention of researchers in recent years. In a systematic literature review on the management of climate change risks in global supply chains by Ghadge et al. (2020), 90 interdisciplinary articles were reviewed between 2005 and 2018. It is seen that more than 30% of these studies were carried out between 2015 and 2018. A large number of studies have been carried out on food supply chains, which are among the areas where the effects of climate change are seen most rapidly. Godde et al. (2021) studied the effects of climate change on animal based food supply chains and emphasized that climate change will have effects throughout the supply chain, from agricultural production to storage, transportation and human consumption.

Parajuli et al. (2019), in face of climate change investigated how fruit and vegetable production supply chains could remain environmentally sustainable. In order to reduce possible losses in the processing chain due to extreme and variable weather conditions, they suggested increasing the capacity of processing facilities such as storage, transportation and logistics in the supply chain. Pankratz and Schiller (2021) investigated climate change and adaptation in global supply chain networks and suggested that extreme weather events in the regions where suppliers are located lead to a decrease in the operating performance of suppliers and their customers.

Izaguirre and her colleagues (2021), in their study investigating climate change risk to global port operations, revealed coastal flooding and overflows caused by sea level rise and heat stress effects of high temperatures as the main factors affecting port operations. In their research Becker et al. (2018), examining the effects of climate change on maritime, they recommended that a wide range of stakeholders operating in ports and related supply chains be in communication regarding adaptation to climate change. In their literature review research Ryley et al. (2020), examining the effects of climate change on aviation, they emphasized the importance of the participation of more stakeholders operating in the aviation industry in the development and implementation of adaptation plans against climate change risks. Their research on adapting railway maintenance to climate change, Garmabaki et al. (2021) concluded that it is important to implement effective climate adaptation approaches, including awareness.

In the context of the effects of climate change, although industries such as supply chains, maritime and ports, aviation and railway are examined separately, the effects of climate change on all modes of transport are clearly lacking as a whole and there is an obvious need for a general framework. To address this research gap, supply chain and logistics operations are considered as a whole in this study.

3. CLIMATE CHANGE

Natural disasters have occurred throughout history. However, it is now becoming more frequent, more intense, and more importantly, more predictable.

Climate change refers to long-term changes in the Earth's local, regional and global temperatures and weather patterns. Global warming, which is used in the same sense as climate change, but is one of the consequences of climate change, is caused by the use of fossil fuels, which increase the levels of greenhouse gases that trap heat in the atmosphere and increase the average surface

temperature of the Earth as a result of human activities. These temperature increases, directly or indirectly caused by humans, are generally called global warming (URL 5, URL 6.)

Especially in the 20th century, the rapid increase in industrialization and the ability to travel around the world with unprecedented efficiency, the ability to trade commodities and share information have accelerated global warming. According to estimates, about 90% of world trade is transported by ships. In 2019, 11 billion tons of goods were loaded at world ports and the global trade value of goods exported to the whole world was approximately 19 trillion US dollars (URL 7). Humanity has depended more and more on fossil fuels since the Industrial Revolution 200 years ago. Carbon dioxide emissions from fossil fuels have increased steadily since then, accumulating in the Atmosphere, warming the planet, and net emissions have increased by 40% over the past 30 years (URL 8). Although the subject of this study is the impact of climate change on supply chains, the global greenhouse gas emissions caused by the sectors are shown in Figure 1.

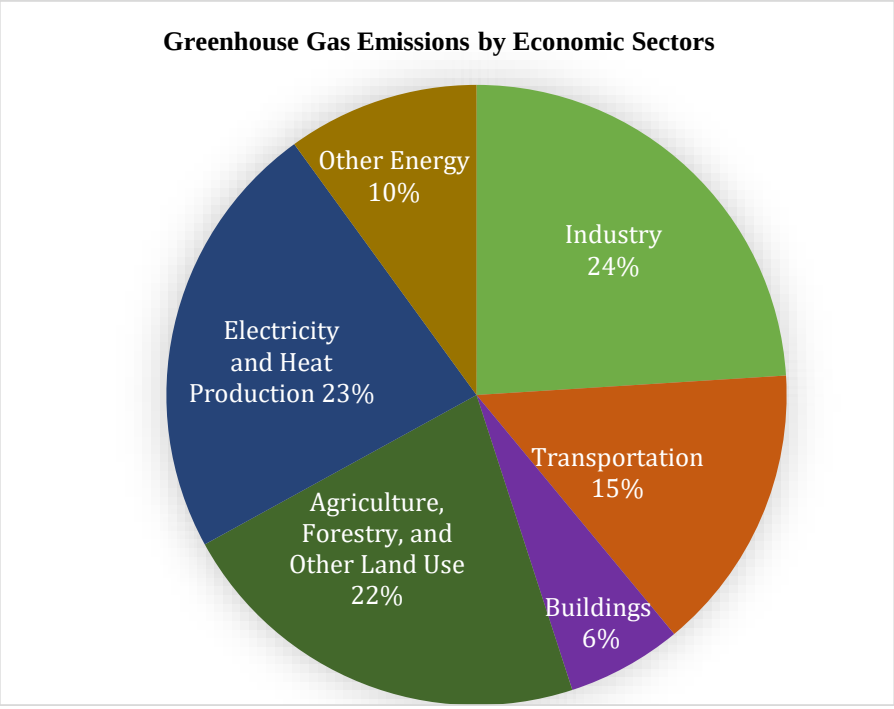

Figure 1.Greenhouse Gas Emissions by Economic Sectors (URL 9)

Climate change makes itself felt with different dangers and these dangers affect businesses in different parts of the world in very different ways (Table 1).

The potential threats of climate change are given in Table 1. Many of these threats continue to threaten societies and businesses in different geographies.

The Intergovernmental Panel on Climate Change (IPCC) was established in 1988 by the World Meteorological Organization (WMO) and the United Nations Environment Program (UNEP) with the goal of providing scientific data to all levels of government for the development of climate policies. With the founding of the IPCC, the process of developing global action to manage climate change began more than three decades ago. The IPCC was created to offer a concise scientific

summary of what is currently known about climate change. It has produced six main evaluation reports in 1990, 1995, 2001, 2007, 2014 and 2022.

Table 1. Operations Risk Indicators (Mazzacurati et al., 2017)

Climate Hazard	Description	Potential Business Impacts
Heat Stress	Increase in temperature	• Rising costs of energy for cooling • Heightened risk of brownouts/power outages • Decreased labor productivity • Negative impacts on human health/ labor force
Water Stress	Fluctuation in water supply and demand	• Reduced supply/ Increased costs • Interrupted business • Damaged reputation • Losted jobs & customers
Extreme Precipitation	Events of heavy rain	• Impairment of Property and Infrastructure • Compromised infrastructure • Delayed projects • Disrupted operations
Wildfire	Change in fire conditions	• Constant decline in property value • Increased insurance losses
Sea level rise	Elevated storm surge, intensified by the escalation of sea levels.	• Flooding problems and damaged physical assets • Permanent loss of property value • Costs of moving operations
Cyclones, Hurricanes, Typhoons	Exposure extreme weather phenomenon	• Severe property damage • Constant decline in property value • Costs of moving operations • Losses in value added operations
Socio-economic vulnerability	Social upheaval, population movement or economic disruption exacerbated or intensified by the influences of climate change	• Disruptions in operations, physical assets damages • Impact on on the labor force • Social acceptance to operate

The United Nations Framework Convention on Climate Change (UNFCCC) was created at the Rio Earth Summit in 1992 to coordinate action on climate change. UNFCCC parties have met annually at Conferences of the Parties (COPs) since 1995. COP 1 was held in Berlin, with an agreement on "Jointly Implemented Actions", the first joint measures in international climate action (Breidenich et al., 1998). The third COP was held in 1997 in Kyoto and the Kyoto Protocol, which entered into force in 2005, was adopted. The Paris Climate Agreement was signed at COP 21 held in Paris in 2015. The COP26 UN Climate Change Conference, which was planned to be held in Glasgow in 2020 by the UK in partnership with Italy, was postponed due to Covid-19 and held in 2021. The COP27 took place in 2022 in Egypt and The COP28 held in Dubai, the United Arab Emirates (UAE) in 2023. The COP29 is scheduled in Bakü, Azerbaijan in November 2024.

4. IMPACT ON SUPPLY CHAIN

Lambert et al. (1998) defined the concept of supply chain, which has many different definitions in the literature, as the harmony of companies that bring products or services to the market. Supply chain management, on the other hand, is the coordination of activities within and between vertically linked firms in order to profitably serve their end customers (Larson and Rogers, 1998). According to The Council of Supply Chain Management Professionals (CSCMP), ''*Supply chain management encompasses the planning and management of all activities involved in sourcing and procurement, conversion, and all logistics management activities*'' (URL 10). As can be understood from the definitions above, the activities of processing raw materials in any corner of the world in different geographies and serving them to consumers in many different places constitute the subject of the supply chain. With the decrease in transportation costs for the last 50 years, developments in communication technologies and the spread of just-in-time production philosophy, outsourcing has increased and production can be made in geographies that are far from the markets. Such a level of complexity and interconnectedness of supply chains reduced costs considerably when things were on track, but in the case of a risk, this supply network can pose great challenges to businesses. The most severe of these difficulties was witnessed by the whole world in the Covid 19 pandemic. In addition to the pandemic, the gigantic container ship agrounded in the Suez Canal almost brought Asia-Europe trade to a halt.

The supply chain does not only cover production and supply activities, but also includes other activities such as transportation, warehousing and retail, as understood from the above definitions. These core activities cover other components such as people, technology, knowledge transfer and adding value. Exposure of the activities and components of a supply chain to one of the climate change factors at any point in the world can bring the entire operation in the chain to a halt.

In fact, nature's disruption of supply chains is not a new phenomenon. Dealing with extreme weather events such as floods, droughts and storms began long before corporations became popular in the 19th century. For many firms, the physical impact of climate change will affect them more through disaster-affected suppliers or flooded transportation routes, rather than their own operations (URL 11). The Western Pacific is home to a significant portion of semiconductor supply chains, with the probability of devastating hurricanes occurring once in 100 years likely to double or even quadruple by 2040. Such hurricanes have the potential to wipe out about 30% of their income by causing months of production loss for businesses in the geography where they occur. Heavy rare earth mining in Southeast China is also likely to face major challenges with the increased probability of heavy rainfall (URL 12).

The increasing effects of climate change have led governments, businesses and other stakeholders to take steps towards climate change. Established at Stanford University in 2022, the School of Sustainability will focus on a range of disciplines, from research to new technologies and climate policy study (URL 13). On the other hand, in an open letter ahead of the G7 summit in Germany in 2022, more than ten global big company executives called for ambitious government climate policies that offer clarity and stability to the private sector (URL 14). These developments are examples of the steps taken by different sectors towards climate change. Climate change factors such as the steps taken by governments and the changing purchasing behavior of consumers pose threats and opportunities to businesses and supply chain networks (Figure 2) (Dasaklis and Pappis, 2013). In a study conducted in 28 countries in 2019, 69% of the participants said that they made a change in consumer behavior due to climate change concerns (URL 15).

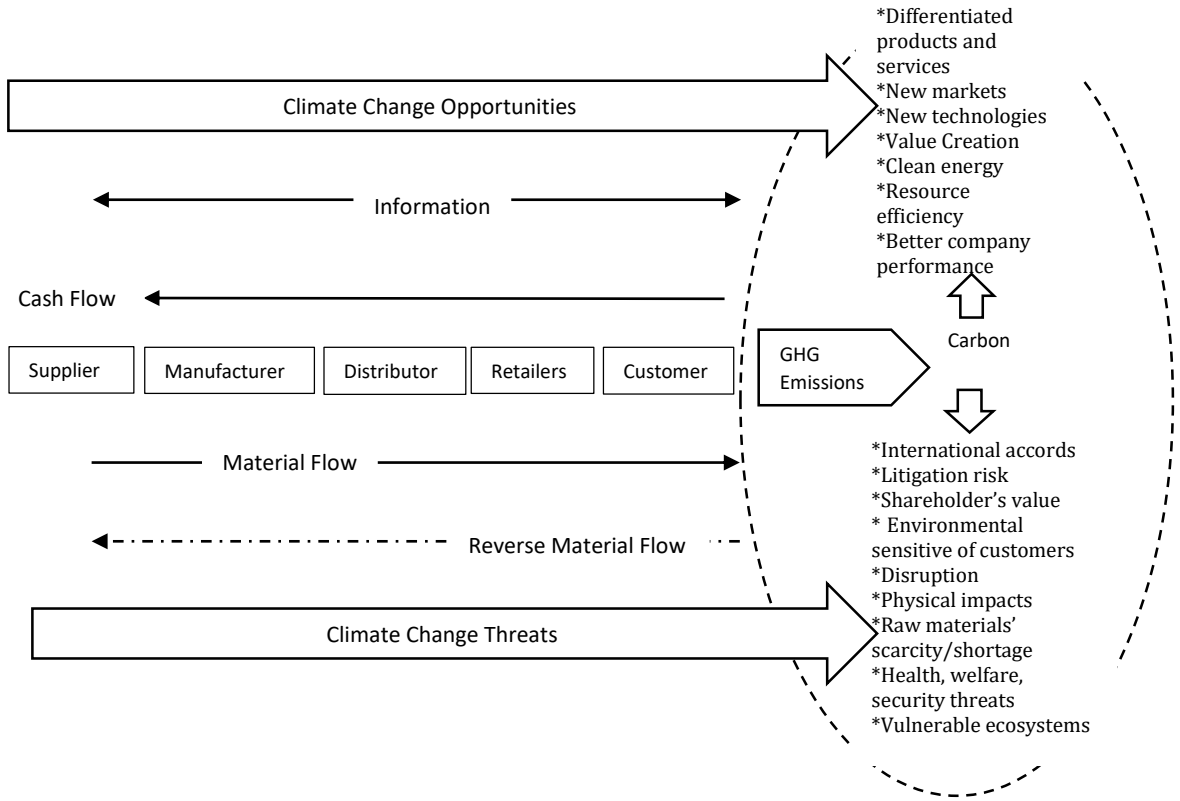

Figure 2. Climate Change Threats and Opportunities for Supply Chain Networks (Dasaklis and Pappis, 2013; URL 9, URL 16)

4.1. Production and Storage

The factors required for production are labor, capital, land and entrepreneurship (Karagül, 2014). Climate change has the potential to affect all of these factors. If the living areas of the employees in the production centers are affected by natural disasters, it is inevitable that the businesses they work will also affect them. On the other hand, societies had to migrate from their places of residence due to extreme weather conditions. Between 2008 and 2016, abrupt weather events like floods, storms, forest fires, and excessive temperatures resulted in the forcible displacement of 21.5 million people annually on average (URL 17).

International management consulting firm McKinsey has grouped the socioeconomic impact of climate change in a five-system framework: livability and workability, food systems, physical assets, infrastructure services and natural capital (URL 18).

Of the hazards listed in Table 1, the temperature factor may affect people's ability to work outdoors. Between 1992 and 2016, approximately 70,000 workers were seriously injured and more than 700 lost their lives due to extreme heat in the USA (Tanglis and Devine, 2018).

Physical assets such as buildings that constitues production centers of enterprises can be damaged or destroyed by dangers such as excessive precipitation, floods and forest fires. In 2011, more than 270 factories were damaged in five industrial estates in the flood disaster that occurred in Thailand (URL 19). Infrastructure services are also damaged due to extreme weather events. Other energy production and transmission tools, especially electricity and natural gas services,

suffer, too. According to the IPCC's 6th Assessment Report (URL 9), the hotter summer climate in Asian countries and the increasing population cause a rapid increase in the demand for energy for cooling (URL 20). For example, the Japanese government, after warning in March 2022, called on businesses and people in the Tokyo area to cut electricity use with a second warning in June, as the heat wave increased the use of air conditioners.

Climate change is changing ecosystems and destroying natural capitals such as forests and oceans that contribute significantly to societies. Because trees keep greenhouse gases out of the atmosphere, forests are critical to limiting the damage of climate change. Agriculture, forestry and related sectors contribute 21% of global greenhouse gas emissions, of which 45% come from deforestation for economic activity (URL 20). Global Canopy, one of the non-profit environmental groups, analyzed the environmental programs of 350 companies working in the forestry, land use and agriculture sectors, which have a major impact on the world's forests, within the framework of the United Nations' Race to Zero 2030 breakthroughs. It has been found that 148 of these companies have committed to net zero, but only nine have made strong progress in preventing deforestation (URL 21) In addition, leaders of Unilever and Nestlé companies in the global food industry have committed to achieving deforestation-free supply chains by the end of 2025 (URL 22).

In today's international trade, raw materials and intermediate products are brought together from different parts of the world with the philosophy of just-in-time manufacturing and presented to the end user. Certain products have clustered production centers in certain countries or even in different regions of these countries. Risks increase when suppliers are clustered in certain regions. About 70% of the world's smartphones are concentrated in one region of China. Another region is home to half of global laptop production (URL 23). The world has witnessed this problem in the latest Covid-19 outbreak. It is estimated that at least 51,000 companies operating in different parts of the world have a first-tier supplier in the Wuhan region of China, where the pandemic first appeared, and at least five million companies around the world have at least one second-tier supplier (Çevik and Durukan, 2021).

Severe freeze in Texas in February 2021 caused the largest power outage in US history. These cuts have exacerbated the semiconductor shortage triggered by the global pandemic, and key suppliers of the automotive industry dependent on microchips have had to close their factories (URL 24).

Sea level rise is one of the most important effects of climate change. Future rates of sea level rise have caught the world's attention. Countries, particularly those in low-lying areas and small islands, are worried that flooding and coastal erosion would limit their land area, and at worst, a sizable portion of their population may be compelled to emigrate (Mimura, 2013).

According to the United Nations report, approximately one in ten of the world's population lives in coastal areas less than 10 meters above sea level, and approximately 40% of the world's population lives in an area 100 km from the coast (URL 25). Sea level rise is considered the most serious threat that climate change poses to China's coastal regions. Over the past century, China has experienced a sustained trend of sea level rise, with a total rise in sea levels of about 20-30 cm and an average annual rise of 2.5 mm (Cui et al., 2018). China's 11 coastal provinces occupy only 13.5% of the land area, accounting for 45.22% of the national GDP and more than 41% of the population by 2021 (URL 26).

Damage to structures, equipment, vehicles used for transportation, raw materials, components, and products, as well as decreased or suspended production, have an immediate impact on many

medium-sized businesses. The main reason for this is that the machines are permanently installed, which can hardly be protected if water enters the first floor. Therefore, production will be interrupted rapidly (Leitold et al., 2021). The increase in production in the world and the growth in e-commerce have increased the number of warehouses and transfer centers. These centers, where raw materials, intermediate products and final products are stored, are generally large closed areas and characteristic structures that are not very high from the ground. These facilities are vulnerable to flooding and extreme weather events. Electricity, natural gas and telecommunications infrastructures are the backbone of both generation and storage facilities. Recent studies show that when power outages are included, economic losses from flood-induced business disruption are 300% higher (Koks et al., 2019). Droughts in recent years have seriously damaged electricity production. Severe storms will damage fragile power grids and natural gas supply systems that is not designed to operate at certain temperatures. Similarly, it will damage critical equipment in gas and coal power plants, wind turbines and pipelines, disrupting critical infrastructures of generation and storage systems.

Extreme heat and drought as a result of climate change affect many different regions from the European continent to China. According to the report of the European Union Joint Research Center, Europe is experiencing the driest time of 500 years in August 2022 and more than 60 percent of land in the EU is under drought warnings or alerts (URL 27). Drought seriously affects agriculture, energy and global material production. Cooling water is of vital importance for thermal power plants that provide about 80% of the world's electricity. In the USA, it is estimated that 41% of the amount of fresh water used in power plants in 2005 was used for electricity generation, primarily for cooling (Zhou et al., 2018). China, which has been heading towards a water crisis in recent years, has 20% of the world's population but only 7% of the world's fresh water resources. The country, which is the production center of the world, is structurally insufficient in water resources and electrical power to sustain its economy (URL 28). The longest river in Asia, the Yangtze, reached a record low, causing major companies such as Toyota and Foxconn to shut down factory operations for at least a week due to outages in hydroelectric power plants (URL 29). Considering the weight of the country in the global economy, potential water-related disruptions that started in China will shock the food, energy and material markets around the world and create economic and political turmoil in the coming years (URL 30).

High temperatures, which reduce productivity, tend to reduce both agriculture and manufacturing exports, and hurricanes, which reduce national incomes, tend to reduce imports. The spatial distribution of climatic conditions in extensive trade networks has the potential to have an impact on market pricing through both effects on supply costs and affects on demand (Carleton and Hsiang, 2016).

4.2. Transportation

Transport is an important sector that contributes to the smooth functioning of societies and ensures the economic development of a nation (Vajjarapu et al., 2019). The lockdown periods that started with the Covid 19 pandemic once again emphasized the great importance of the transportation industry. The transportation sector, which is in a key position to ensure an uninterrupted flow of goods and the continuation of world trade, needs to be prepared in advance for the increasing effects of climate change day by day. Climate change impact types and possible consequences in terms of transportation are given in Table 2.

Table 2. Types of Climate Change Impacts, Possible Consequences for Transport (Nemry and Demirel, 2012)

Climate impact	Overview of potential impact on transport system
Increased Summer Temperatures	• Deterioration of asphalt, Railway Track Expansion, change in the takingoff distance and required airport runway length, lack of navigable water, thermal expansion of bridges, superheating of diesel engine
Increased Winter Temperatures	• Alleviating limitations on road and rail maintenance • Modified construction seasons
Increased Precipitation and floodings	• Inundation of terrestrial transportation infrastructures, dampened road surfaces, and hazards to safety. • Erosion of embankments, scouring of bridges, and submergence of subterranean transit systems. • Increased occurrence of slushflow avalanches, landslides, and related vulnerabilities.
Increased and more frequent extreme winds	• Impairment of transportation-related infrastructure such as roadways, railways, pipelines, maritime ports, and aviation facilities. • Vulnerabilities in cable-supported bridges, signage, elevated cables, railway signaling, and towering structures. • Disruption of electronic transportation infrastructures including signaling systems. • Diminished safety conditions for vehicles driving.
Sea Level Rise and sea storm surges	• Degradation of coastal highways due to erosion. • Elevated tides posing threats to port and harbor installations, as well as low-level aviation infrastructure. • Recurrent and sustained inundation. • Scouring of bridges. • Deterioration through corrosion.
Change in frequency of Winter Storms	• Less or more snow / ice for all modes
Permafrost degradation abnd thawing	• Road, rail, airport, pipeline embankments failures
Reduced Arctic sea ice Cover	• New northern shipping routes Reduced ice loading on structures, such as bridges or piers
Earlier River Ice Breakup	• Ice-jam flooding risk

Climate change is likely to threaten transportation systems both temporarily through extreme weather events and permanently through gradual changes (Markolf et al., 2019). Sudden extreme weather events, floods and landslides can increase the risks of disruption in transportation systems such as delays, disruptions, damage and malfunctions. Gabela and Sarmiento (2020) investigated the effects of the 2013 floods in Germany on road freight transport and found that 23% of all main roads were damaged during floods. A study of the effects of the climate crisis on critical infrastructure found that high temperatures alone will account for around 92% of total hazard damage in Europe's transport sector by 2080, largely as roads are built for cooler times. (Forzieri vd., 2018). The increase in the number of floods and excessively snowy days on the highways will shorten the economic life of the roads. More frequent maintenance, repair and rebuilding activities will result in higher costs. For example, the African continent faces a cost of US$183.6 billion to repair and maintain roads as a result of damage from temperature and precipitation changes from potential climate change by 2100 (Chinowsky et al., 2011).

Extreme weather events cause great risks to rails, bridges, tunnels, energy and communication systems, and extreme temperatures cause rails to buckle in railways and trains to derail or collide

(Rail Safety and Standards Board, 2003). In 2021, the financial impact of wildfires and heavy rains on Union Pacific, North America's largest rail freight company, was approximately $100 million as it caused gradual disruptions to the company's 32,000-mile network (URL 31).

Climate change also affects airport operations in different ways. The terminal and flight operations will need to be modified due to variations in wind speed and direction, temperature, and air density (Williams, 2016). In the "Climate Change Risk and Resilience" report prepared by the European Air Navigation Safety Organization (Eurocontrol) (2013), the main potential risks of climate change for the European aviation sector are as follows;

- Temperature increase
- Changes in precipitation (rain and snow)
- Changes in storm patterns
- Changes in wind patterns
- Sea level rise and storm surges

Analyzing the infrastructure of more than 14,000 airports worldwide and their exposure to storm surges for current and future sea level, Yesudian and Dawson (2021) concluded that 269 airports are currently at risk of coastal flooding. According to the aforesaid research, a temperature increase of 2°C in line with the Paris Agreement will cause 100 airports to remain below the mean sea level and 364 airports to face the risk of flooding. Airport operations may be interrupted or halted by flooding of airport terminals, electricity and lighting infrastructure, navigation and communication systems, inter-terminal transit, or runways. Because important utility infrastructure is frequently underground, minor water leaks can harm fundamental components (Burbidge, 2018). There are risks of climate change causing the following problems in aviation operations (Eurocontrol, 2018);

- Aircraft performance changes
- Runway length issues
- Efficiency and flight range problems
- Demand redistribution (geographic)
- Redistribution of demand (seasonal)
- Increased cooling and heating requirements
- Heat damage to airport surfaces (runways and taxiways)
- Structural problems caused by changes in permafrost

Ports, which are the driving force of economic growth and development, play a significant role in meeting human needs and in global trade. As more than 80% by volume of global trade in goods are transported by sea, ports are crucial links in production, distribution and supply chains based on low-cost transportation (URL 32). In 2021, the cargo and shipping activities of ports on the US west coast supported more than 12 million jobs across the US and a total economic value of approximately $2 trillion, accounting for approximately 8.7% of the nation's GDP (Martin Associates, 2022). Ports are highly vulnerable to extreme weather conditions due to their nature being built at sea level and serving in open areas. Disruption of port operations, with damage to port infrastructures and equipment, will lead to disruption of supply chains and disruption to trade globally. Hurricane Sandy, which hit the ports of New York and New Jersey in 2012, disrupted maritime operations and facilities and caused approximately $2.2 billion in damage (Smythe, 2013). In general, the maritime sector is affected by the increase in sea levels in port activities and the increase in the severity of storms in voyage services (Asariotis and Benamara, 2012).

River transport, known as inland waterway transport, is also affected by extreme temperatures with changing climate, similar to other modes of transport. In Europe, transportation could not be carried out due to the fall in the water level in 2018 in the Rhine River, which connects Germany and Switzerland to Rotterdam. Approximately 80% of inland waterway transport, which constitutes 6% of Germany's total transport volume, takes place on the Rhine, the most important inland waterway in Germany and Western Europe (Ademmer et al., 2020). The water level of 80 cm, which is necessary for the safe floating of the barges used in river transport, has decreased to 25 cm. The banks of the river, which is approximately 1200 km long, are home to some of Germany's largest industrial companies, including the world's largest chemical plant. The suspension of river transport due to drought caused industrial plants to cut production for several weeks and gave the German economy a short-term shock (URL 33). In August 2022, the water level dropped to 47 cm and the container ships had to carry some of their planned cargoes to avoid running aground, resulting in high transportation costs and serious delays in deliveries (URL 34).

Although global warming negatively affects humanity, the melting of glaciers offers new business opportunities in the Arctic region. Since the geographical distance between the continents is less in the Arctic than in the southern regions, northern countries have started to build submarine fiber optic cables in Arctic waters (URL 35). Furthermore, new transportation routes are emerging as an alternative to the Suez Canal and Cape of Good Hope crossings in the Arctic region. Alternative new routes in the North Pole provide approximately 35% distance savings compared to traditional maritime trade routes (Çevik and Durukan, 2020).

4.3. Insurance

Climate change also affects the insurance industry. Businesses transfer the risks brought by extreme weather conditions to insurance companies and as the risks increase, the premiums paid increase. Between 1980 and 2020, extreme weather events caused 487 billion Euros of economic loss in the member states of the European Environment Agency and accounted for approximately 80% of the total economic losses caused by natural disasters (URL 36). Global economic losses from natural and man-made disasters increased from USD 150 billion in 2019 to USD 202 billion in 2020. Estimated global insured losses from natural disasters in the first half of 2022 amounted to USD 35 billion, exceeding the average of the last decade by 22% (Swiss Re, 2020; URL 37). The increase in pandemics and natural disasters in recent years has also negatively affected reinsurance companies, and some reinsurance companies have implemented a 12% premium increase in property and casualty insurance, which includes natural disaster insurance and other types of insurance, in July 2022 (URL 38).

4.4. Other Logistics Activities

Logistics activities include transportation, stock management, warehouse management, packaging, order processing, handling, customs clearance, customer services, information management, demand forecasting, after-sales service, factory-warehouse location selection, purchasing, and waste parts management. Transportation, stock management and warehouse management are considered as the prominent basic logistics activities. These three activities are the key activities carried out within the entire logistics channel (Nalçakan and Er, 2012) .

Since these logistics operations (packaging, order processing, handling, customs, etc.), other than basic logistics activities, are generally carried out in closed areas, extreme weather events primarily affect employee. Inadequate ventilation, heating and cooling systems of buildings will negatively affect the workforce (Yavuz et al., 2020). Extreme temperatures may negatively affect electrical infrastructure, digital systems and power supplies, and these interruptions may disrupt

business processes. Extreme weather events may hinder activities such as transportation, support and personnel recruitment carried out before and after these operations.

Inventory control management has a strong impact on the performance and profitability of the firm, increasing efficiency and reducing costs in the supply chain process (Khan and Siddiqui, 2019). Increasing extreme weather events may lead to increased transportation costs, which in turn may lead to increased raw material acquisition costs. To fulfill production contracts and maintain production, businesses may consume raw materials and intermediate products faster than planned, ultimately reducing the inventory of unfinished products. Climate impact increases the likelihood of road closures and traffic stops, reducing the speed at which finished products reach customers, resulting in product backlogs and a significant increase in finished product inventory (He et al., 2023).

Since customs revenues arise mainly from customs duties, taxes and duties applied to goods subject to import and export, climate change may have various impacts on these revenues. Disruptions caused by climate change, such as extreme weather events, prolonged droughts or floods, can disrupt supply chains and business models, ultimately reducing trade volumes and therefore customs revenues (Soro, 2023).

The number of climate elements that concern the company affects the positive financial performance of companies. Businesses that are less dependent on the natural environment may continue normal business operations and therefore experience positive sales growth, whereas businesses that are highly dependent on weather conditions will, conversely, experience a decline in sales (Bergmann et al., 2016).

Extreme weather events caused by climate change can cause disruptions to supply chain facilities, changes in workforce productivity, variability in demand and declines in delivery performance. These problems in supply chains multiply exponentially throughout the network, leading to reduced efficiency, profits, delivery times and therefore order fulfillment. The fact that climate change affects both the internal and external environment of the business in unexpected ways causes problems in achieving planning and forecasting goals (Er Kara et al., 2021).

Packaging has a critical role in the storage, transportation and handling of products, and in protecting and preserving the products (URL 39). However, unexpected sudden changes in weather conditions can affect packaging materials and compromise their ability to keep the products inside safe. Changing weather conditions such as extreme temperature and humidity during transportation of the products will negatively affect products that spoil quickly due to packaging that loses its function. Employees serving in this area will be negatively affected by extreme weather events.

5. METHOD

In this study, literature review and expert interview technique, one of the qualitative research methods, was used to reveal the effects of climate change on logistics and supply chains.

This study's data came from secondary information made available by primary research in related field. In recent years, secondary data has grown in significance for study in a variety of fields, including sociology, economics, and political science (Trzesniewski et al., 2011). The researchers

answered crucial research concerns by analyzing secondary data in a way that broadened or reinterpreted key findings in the area (Greenhoot and Dowsett, 2012).

Expert interviewing, as a qualitative research method that aims to explore or collect data on a particular area of interest, has been a frequently used method in political and social research since the early 1990s (Döringer, 2021). Interviews are the most commonly used data collection method, and the semi-structured format is the most frequently used interview technique in qualitative research (Kallio et al., 2016). According to Mergel et al.'s (2019) definition, an expert is a person who possesses technical, procedural, and interpretive knowledge relevant to their fields of expertise.

The advantages of using expert interviews, which have long been popular in social research, for the researcher are as follows (Bogner et al., 2009);

- Talking to experts during the discovery process of a study is a more efficient and collective method of collecting data than quantitative surveys.
- Interviewing experts can help shorten lengthy data collection processes, especially because experts provide practical knowledge from within the organisation.
- Interviewing experts is appropriate when it is difficult or impossible to access a particular social area
- Additionally, if the expert being interviewed also holds a key position in the organization, opportunities to expand the researcher's access to the field may be uncovered during this interview.

In qualitative research, the adequacy of sample size is relative; While a sample size of 10 is sufficient for certain types of homogeneous or critical case sampling, it may be considered too small to develop a complex phenomenon or theory (Sandelowski, 1995). There is no exact number of samples that researchers should include in their studies. However, it is recommended that researchers include at least 8 to 15 participants to obtain a large enough sample so that they can determine whether their findings are representative of more than one person (Hill et al., 1997).

10 experts were interviewed in the research. The interviewees who participated in the research were coded as P1, P2, P3... with the letter ''P'' meaning ''participant''. Interviews were conducted face to face and by telephone in February/March 2024. Interviewees were promised anonymity in any publication and as a result only identifying them by their role in their organization.

In this study, it is aimed to answer the following research questions in particular:
RQ1: What is the impact of extreme weather events on logistics operations?
RQ2: How does climate change affect supply chains in general?

Although this research focuses on supply chains, it is expected to contribute to the literature on its effects on international logistics activities.

6. RESULTS

In order to determine their perspectives on the effects of climate change on logistics and supply chains, two questions were asked to the managers and employees of production, transportation and warehouse companies; one question was asked to employees in the customs, packaging, handling and delivery business and an occupational health and safety (OHS) expert in Turkey.

RQ1: What is the impact of extreme weather events on logistics operations ?
RQ2: How does climate change affect supply chains in general?

P1: (Mid-level manager in warehouse industry)
A1: *"Especially heavy rains in recent years caused floods, causing minor damage to our warehouse. We know that some of our friends in the industry have had more than one flood in their warehouses. Even though there are no problems in our warehouse on extremely rainy days, the vehicles that bring goods to and from the warehouse experience delays due to floods and puddles on the roads. Furthermore, our friends we have talked to in the industry say that extreme heat, especially in the summer months, has increased the energy costs of cold-storage warehouses."*

A2: *"As I mentioned, when excessive rainfall affects the transportation infrastructure, it becomes difficult to reach ports or factories, it can disrupt the transportation of raw materials or inputs to factories, logistics processes, and cause delays in supply chains. It causes businesses to change their plans and sometimes even cause financial losses."*

P2: (Mid-level manager in production)
A1: "*We operate a factory that processes agricultural products. Farmers or brokers bring us the grains. However, in some rural areas, we send trucks to farmers who want to send their grain to our factory. The bridge that provides transportation to the village was damaged due to the flood and we cannot bring the product. Or the farmer cannot take machinery to his field for harvesting."*

A2: "*Heavy rains during the grain harvest season not only reduce the quality of goods but also cause producers' products to be flooded. Prices vary widely locally during periods of floods or heavy rain during peak harvest season. There are grain silos in our factories. We know that silos in some places have been damaged in strong storms in recent years. The industry now attaches importance to the durability of buildings."*

P3: (Mid-level manager in railway company)
A1: "*In railway transportation, transportation cannot be carried out when floods damage the ground on which the rails are laid. During periods of heavy rainfall, soil or rocks may fall on the rails as a result of landslides. A similar event occurred was in 2024. In fact, although extreme heat does not affect our entire line, it mostly affects the line in the southern regions. Heated rails expand and can start to curve this is known as buckling, which can lead to accidents. In addition, since our employees in some units work outdoors, there is a risk of health problems in extremely hot weather."*

A2: "*In general, considering Turkey's railway lines, alternative routes are used in case of road interruption in any region. However, this alternative route can sometimes cover very long distances. In this case, the sender of the goods has to bear serious costs. In addition to the cost, the time also increases. The plans of the sender's recipient customer may be disrupted. If some of the loaded wagons are damaged on the road, the production of the recipient company may be disrupted."*

P4: (Mid-level manager in airline company)
A1: "*Weather is an important data source for aviation. Uncertainty in weather forecasts or sudden changes can make the weather's suitability for flight unpredictable. Such situations can make flight planning and flight route selection difficult. Excessive rainfall may damage the apron or infrastructure. I don't remember any large-scale incident in Turkey where the apron was affected by floods, but we know that floods have occurred at airports in different countries in recent years. Extreme temperatures can sometimes be a problem for employees working on the apron. Strong storms can cause equipment on the apron to move and crash into aircraft. Since all these disruptions*

ultimately concern the passenger, they affect your service quality and customer satisfaction. Cancellations and delays can cause undesirable situations such as chaos at airports.''

A2: ''*When we look at the characteristic features of air cargo transportation, these cargoes are valuable, sensitive and must be transported quickly. In cases where airports cannot provide service due to long-term extreme weather events, these cargoes will not reach their recipients on time. Especially today, some inputs of companies that produce in just-in-time production model are transported by air cargo. In this case, there will be a risk of the production line halting. Additionally, race horses or Formula 1 racing vehicles are also transported by air. These organizations are of worldwide importance. When we look at air transportation from the passenger perspective, business travel has a significant share. Time is important for senior executives who hold business meetings in different countries of the world. Delaying the flights of these executives may lead to business losses.''*

P5: (Executive in road transport company)
A1: ''*On rainy days, intercity main roads do not cause much trouble, but district roads or bridge crossings may flood. While passing through mountainous regions, rocks or soil from the mountain block the road. In this case, we have to wait. If there is a facility nearby where we can park for a long time, we wait there, but otherwise we have to stay in the truck on cold days, in which case we experience fuel problems. If we get caught in snow or rain in the city, there is long traffic. When the weather is very hot in the summer, asphalt melts and this negatively affects us drivers.''*

A2: ''*When it rains or snows a lot, if we are on the road, we are forced to reduce our speed. Of course, this delays the delivery of cargo. We have had disputes regarding delay in freight delivery several times. When the weather is too hot or too cold, the loads we carry can be affected. Of course, no one wants their good to be damaged.''*

P6: (Mid-level manager in port operation)

A1: ''*By their nature, ports are located at flat areas and seaside. They are vulnerable to winds and floods. Excessive rainfall can cause floods. Even if there is no puddle in the ports, it can affect traffic on the roads accessing the ports. Extreme winds can blow empty containers in ports or knock down cranes that load and unload containers, restraining operations. Similarly, there may be a risk of containers falling from ships traveling at sea. In general, excessive rains and winds can stress operations in ports.''*

A2: ''*These factors affecting maritime transportation can generally interrupt transportation and port operations and cause delays. These negativities are reflected in transportation costs and insurance expenses. The entire supply chain can be negatively affected in terms of both time and cost. Interruption of port operations can cause delays. When the goods are delayed in reaching their destination, the inputs of the manufacturing enterprises are delayed and production plans can be disrupted.''*

Q: What is the impact of extreme weather events on logistics operations ?

P7: (Staffer in custom operation)
A: ''*During the summer season, extreme heat does not affect the operations and passage of commercial vehicles and individual vehicles. If the vehicles have entered the customs area, border crossing and customs procedures are carried out. However, there may be some difficulties for the working staff. Some of our colleagues have experienced cases of sunstroke, but support personnel are immediately assigned to replace the staff with health problems, services and operations continue*

without interruption. Since customs areas are open and wide areas, they can be exposed to floods. We have experienced floods and flooding in recent years, but since critical systems such as electricity and digital infrastructure were not damaged, there was no disruption in customs procedures. Of course, in the event of a flood that damages these systems, business processes will be interrupted. Excessive snowfall at border gates and customs areas in high-altitude geographical regions causes difficulties for employee in reaching their workplaces.''

P8: (Assistant Professor in Occupational health and safety (OHS))
A: *''Optimum temperature, humidity and wind conditions, which we call thermal comfort in indoor environments, indicate the suitability of the workplace. For light work, the room temperature should be 22-24C°. During heavy work, body temperature increases due to muscle movements producing energy, so the room temperature should be low. Those who work in open areas may be exposed to sunlight and skin disorders may occur in these people. To prevent this, it is necessary to have full personal protective equipment such as mask, glasses and cream. Since the musculoskeletal system will be more sensitive in extremely windy weather, employees working in these conditions are more likely to experience health problems. Monitoring the health of employees by performing periodic health checks in rainy weather and other adverse weather conditions is important for work efficiency.''*

P9: (Staffer in delivery operation)
A: *''Since we go to delivery with open vehicles, which we call motorcycles, extreme temperatures affect us a lot. Likewise, in extremely windy and snowy weather, there are risks of both traffic accidents and diseases. On days when delivery cannot be made, work piles up and drags it to the next days as a workload. Recipient complain about delayed deliveries. During flood events and extremely rainy days, urban traffic is heavy, which delays deliveries too, we have to change routes, and the extra distance increases the fuel cost. When distribution/delivery businesses serving in industrial zones delay deliveries on days when there is a lot of rain or snow, the lack of parts, tools and components needed by industrial businesses disrupts production work. Additionally, since industrial zones are located outside residential areas in some cities, deliveries are made on a certain day of the week. If delivery cannot be made that day, it will be delayed until the next week, resulting in a serious loss of time. Since the delivery/distribution sector generally works with insufficient personnel, there is a lot of workload due to the lack of personnel with health problems, which causes an increase in the workload of other personnel.''*

P10: (Staffer in packaging and handling operationin warehouse)
A: *''Extreme weather events affect the personnel working in packaging, handling and other value-added works and processes in the warehouses (indoor areas). On days when the weather is very hot, if the ventilation or cooling systems of the buildings are inadequate, employees get tired more quickly and their work performance decreases. If the weather is very cold, employees experience health problems more often. Sweating and cold weather during busy working days cause illness. There are similar effects for those who work outdoors. However, there are also health problems such as sunstroke in outdoors. In regions where the winter season is intense, if warehouses or work sites are outside the city, getting to work may be disrupted because snowfall closes the roads.''*

7. CONCLUSION

The global pandemic has wreaked unpredictable damage to supply chain networks, but beyond shipping delays and parts shortages, climate change presents a longer-term challenge for supply chains. Climate change affects a different part of supply chains, as different geographies

experience different extreme weather events due to their characteristic climate characteristics. The business world is deeply interconnected due to international trade. The effects of climate change, which is a systemic problem, will directly or indirectly affect every company. For different companies, this will transform to different costs (URL 40).

This study, which was conducted to investigate the effects of climate change on logistics and supply chains, achieved some important results. First of all, the research results show that extreme weather events resulting from climate change affect operations, in the context of the opinions of participants from different areas of logistics and supply chains. The majority of the participants stated that extreme weather events affected their operations or also affected the previous or post-stage of their operations (in transportation to the operation area or in the transportation of departing vehicles to their next destination). The fact that the majority of business processes in transportation operations are carried out in open areas shows that infrastructure or facilities and especially employees, are vulnerable to extreme weather events. An interruption occurring at one point in the supply chain will affect the entire chain throughout the network, causing businesses to change their production and post-production plans, and will also have a negative impact in terms of cost and time. Careful monitoring of the working conditions of employees in packaging, handling and value-added operations in indoor areas against extreme weather events will prevent possible health problems.

Different hazards arise as a result of climate change, which refers to long-term changes in local, regional and global temperatures and weather patterns. The consequences of climate change, such as temperature change, water stress, excessive precipitation, wildfire, sea level rise, hurricanes, typhoons and cyclones, socio-economic vulnerability, have a variety of potential impacts on different businesses in different parts of the world. The decrease in transportation costs, the development of technology and the globalized production system have increased the connections between producers and consumers all over the world and have made the smooth flow of goods in the supply chains. However, since an interruption in one link of the supply chain will affect the entire chain, it is important for businesses to be prepared for such interruptions in advance. All factors of production are affected by climate change. The forced migration of millions of people due to the sudden dangers caused by weather conditions such as floods, storms, forest fires, and extreme temperatures and the loss of their lives due to these hazards will cause a loss of labor required for production. Physical assets such as buildings that make up production facilities and warehouses can be damaged or destroyed by hazards such as excessive precipitation, floods and forest fires.

The transportation sector, which contributes to the welfare of societies and is an important sector in the economic development of countries, is perhaps the area where climate change first showed its impact. Sudden extreme weather events, floods and landslides disrupt transportation infrastructures and cause interruptions in supply chains. Extreme temperatures damage the railway lines by disrupting the ground on the highways and by causing the rails to buckle in the railways. Similarly, heavy rainfall interrupts both modes of transport. The aviation industry is affected by adverse conditions such as changes in storm patterns and sea level rise as a result of the changing climate. Extreme weather events can cause disruption or interruption of airport operations by damaging power and lighting infrastructure, navigation and communication equipment in airport terminals. Ports are highly vulnerable to extreme weather conditions due to their nature being built at sea level and serving in open areas. Damage to port infrastructures and equipment will cause disruption of operations and halt global trade in ports where 80% of the world's goods trade is handled. A model change has become imperative in the planning,

investment and operation strategies of ports, which operate at the forefront of climate change, at the center of global development, and which are the most important transit route of world trade. The destruction caused by severe weather events in recent years has begun to seriously affect the insurance industry. Large amounts of compensation payments by insurance companies caused reinsurance companies to increase their premiums.

Whether the world warms more or less, societies will need to change the way they live and work. With climate change exacerbating extreme weather events, world societies today have to renew their world architecture and infrastructure for unexpected situations. Making buildings, cities, supply chains, and even agriculture weatherproof is essential to having a chance to live with climate change.

This study, which investigates the operational effects of climate change on logistics and supply chains, is expected to be a stepping stone for further research and to provide a new perspective in investigating the economic effects of climate change on logistics and supply chains

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