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White Paper on European Climate Risk and Trade in Europe



EXECUTIVE SUMMARY

The European Union, home to the world's largest single market and one of the world's most outward-facing economies, is uniquely exposed to transboundary climate change risks due to its close connectivity with other regions and countries. Climate change is expected to increase the costs of international trade by disrupting production and supply chains, with significant social and economic spillover effects to other businesses. It will be costly and complex to adapt supply chains and strengthen trade policies in preparation for climate risks and variability.

The EU is more reliant on international supply chains than most regions, including China and the United States. The effects of climate change on international supply chains present a serious threat to the EU's stability by compromising essential food, pharmaceuticals, and commodity imports, undermining export-driven economic growth and jobs, and affecting the health, safety, and livelihoods of workers and communities that operate supply chains. A climate adaptation-focused partnership between the EU and supply chain actors would ensure broader resilience for workers, suppliers, and their surrounding communities.

The European Climate Risk and Trade policy white paper draws on insights from a series of private sector consultations to identify some of the main barriers that are currently hindering business actions on adaptation. It explores the important role of public policies to create an enabling environment that will accelerate investments in adaptation solutions and scale up their deployment. The paper highlights several key areas for policy action and collaboration:

- Strengthen climate risk assessment and scenario analyses to map current and future climate risks against supply chains in critical sectors, considering compound effects.
- Develop guidelines for physical climate risk disclosure and adaptation-related metrics, to support harmonisation of standards and alignment of regulation. These could be incorporated into existing regulatory frameworks.
- Establish a collaborative platform to facilitate both public-private and business-to-business collaboration around risk sharing and sector-specific co-investments in adaptation in shared supply chains.
- Implement policies to accelerate both public and private investments into adaptation, through increased access to adaptation finance for small-and-medium sized enterprises, and other economic incentives, such as via bespoke corporate grants, tax credits and public procurement.

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1. INTRODUCTION

The European Union is home to the world's largest single market and is one of the world's most outward-facing economies, but its close connectivity with other regions and countries around the globe mean that the continent is uniquely exposed to climate change risks that originate beyond its borders. These transboundary climate risks have become the subject of heightened attention over the last few years due to Europe's high reliance on complex, global supply chains and the increasing frequency and severity of disruption from extreme weather events.

Climate change is expected to increase the costs of international trade by disrupting production and supply chains, with significant social and economic spillover effects to other businesses, both large and small (Verschuur, Koks, & Hall, 2023; Barrot & Sauvagnat, 2015). Further, it will be costly and

The effects of climate change on international supply chains present a serious threat to the EU's stability.

complex to adapt supply chains and strengthen trade policies in preparation for climate risks and variability. There are multiple risks to those nations – both richer and poorer – that are more reliant on imports and exports for stability (Adams, Benzie, & Croft, 2021). The complex links within and across economies make it difficult to predict to what extent an economy will gain or lose competitiveness in each sector as a result of a climate-related shock.

The EU is more reliant on international supply chains than most regions; considerably more so than China and the United States (Szczepański, 2021). The effects of climate change on international supply chains present a serious threat to the EU's stability by a) compromising essential food, pharmaceuticals, and commodities, b) undermining export-driven economic growth and jobs, and c) affecting the health, safety, and livelihoods of the workers and communities that operate supply chains.

It is therefore critical that European governments and businesses work with research institutions and trade partners to take proactive steps to safeguard international supply chains. While a few individual traders have taken steps to brace for supply chain disruptions, a partnership approach would ensure a more resilient, reliable trading system. A climate adaptation-focused partnership between the EU and supply chain actors would also need to ensure that any adaptation actions taken would deliver broader resilience for workers, suppliers, and their surrounding communities.

This white paper contributes to the evidence base on the risks that European trade links and global value chains face from climate change. It presents steps that European governments and business partners must take to manage climate risks. In Section 2, we explore the main channels through which climate hazards can propagate and cause disruptions to international supply chains, as well as their potential effects across sectors. Section 3 discusses potential design weaknesses in today's supply chains that are likely to exacerbate the frequency and severity of climate-induced disruptions in the future. Sections 4, 5 and 6 examine how prepared businesses are to mitigate the consequences of such disruptions; an overview of common strategies and measures adopted by European corporations¹ to accelerate business-led adaptations is presented, as well as key challenges and opportunities. To this end, the paper draws on expert insights from recent private sector consultations conducted across complementary programmes of work, including AWB's European Climate Risk and Trade Policy Forum and bilateral meetings (Mikaelsson, 2022), the UN Global Compact Think Lab on a just transition (Mikaelsson, Dzebo, & Klein, 2023), and the World Economic Forum's business stock take on business-led adaptation (World Economic Forum, 2023). The final sections aim to inform an effective European policy response by presenting important policy options and levers that the EU and Member States can pursue to enhance the climate resilience of European supply chains in a way that is inclusive and fair.

1 European corporations refer to businesses that have their headquarters located in Europe or have a significant operational and commercial footprint in the European market.

2. EUROPE'S EXPOSURE TO CLIMATE RISK VIA INTERNATIONAL TRADE

The EU's international trade is increasingly exposed to climate risks, primarily due to the complex interplay of climate change impacts on infrastructure and trade routes, environmental regulations, and evolving consumer preferences. The EU depends on reliable imports of raw materials, components, pharmaceuticals, machinery, and commodities across many sectors that aim to deliver cost-effective products and services for businesses and households, and to transform these imports into high-value goods and services that support export-driven economic growth. As a result, Europe has become highly dependent on imports from a small number of countries that are becoming increasingly exposed to the effects of climate change.

Europe produces most of its own cereals and vegetables, though it has become increasingly reliant on agricultural commodity imports (especially for animal feed). A 2021 European Commission study showed an 82% increase in agri-food imports between 2005 and 2018 and found the EU to be highly dependent on a wide range of agri-food products (European Commission, Directorate-General for Agriculture and Rural Development, 2022).

Furthermore, many of the EU's agri-food imports are reliant on a small number of so-called bread-baskets – regions with substantial agri-food production as result of advantageous soil and climate conditions. For example, the EU imports 82% of its soybeans and 77% of its soybean meal, with most of its soy imports sourced from Brazil, the US and Argentina, whereas 78% of the EU's palm oil comes from Malaysia and Indonesia. At

the same time, another European study concluded that more than 44% of the EU's agri-food imports will become highly vulnerable to drought in the next 20 to 30 years (Ercin, Veldkamp, & Hunink, 2021).

The EU is also highly dependent on imports from climate-vulnerable countries outside its borders in the pharmaceuticals and critical raw materials sectors. According to the European Parliament's 2020 report on medicine shortages, around 40% of medicinal end-products marketed in the EU originate in third countries (Committee on the Environment, Public Health and Food Safety, 2022). The EU also increasingly relies on China and India for its imports of active pharmaceutical ingredients (APIs), chemical raw materials and off-patent medicines (Directorate-General for External Policies, 2021), with 40% of APIs from China alone. At the same time, pharmaceutical manufacturing sites in these countries have been found to be especially vulnerable to water-related risks, which are accelerated by climate change (Dobson, 2021).

Europe's demand for critical raw materials is expected to rise exponentially over the next few decades, and the EU has become highly reliant on a small number of foreign suppliers to meet its demand: between 75 to 100% of its most-used metals are imported from outside the EU (European Commission, 2022). Around 80 to 90% of global production of heavy rare earth minerals is concentrated within a small Chinese region prone to heavy rainfall and is expected to become increasingly exposed to climate change in the coming decades with serious implications for the

The EU is highly dependent on imports from climate-vulnerable countries outside its borders.

Box 1. Luck, or resilient supply chains? The urgent delivery of millions of Covid-19 vaccines to 185 nations

The Covid-19 vaccine depends on stable, extremely cold temperatures during transportation. Dry ice, sterile packaging, and highly reliable supply chains connecting 185 countries were key to saving nearly 20 million lives in the first year of shipment (Wappes, 2022). A major natural disaster or transportation route bottlenecks affecting the supply chain infrastructure would have had devastating effects, especially in developing countries and difficult to reach small island nations.

supply of heavy rare earth minerals (Woetzel, et al., 2020). Another significant share of the heavy rare-earth minerals is sourced from Myanmar that has been ranked as the second most vulnerable country globally to extreme weather events (Eckstein, Künzel, & Schäfer, 2021). The next section discusses climate risks to the EU's supply chains.

2.1 Climate change and supply chains

Climate disruptions to major supply chains are expected to increase, forcing importers and exporters and supply chain actors to reevaluate and adapt operations (**Table 1**). While rising sea levels is the most significant threat to international supply chain infrastructure through impacts on port infrastruc-

Climate disruptions to major supply chains are expected to increase, forcing supply chain actors to reevaluate and adapt operations.

ture, European countries have been severely affected by supply chain shocks and disruptions caused by increased rates of storms, flooding, heatwaves and droughts along international trading routes.

For example, during the summer of 2023, an unprecedented drought caused major disruptions to the Panama Canal. Hundreds of large freighter ships were delayed by traffic jams in both the

Atlantic and Pacific oceans. So severe was the drought that canal operators decided to limit the number and size of shipping vessels that could pass, resulting in disruptions in trade and shipments of goods to dozens of countries in Europe, Asia, and Latin America.

The Panama Canal is an 82-kilometre waterway constructed to allow ships to pass between the Atlantic and Pacific oceans and its operations are under increasing pressure from changes in climate. The canal depends on a series of rainwater-fed locks that help move ships from one ocean to another. As one of the wettest countries on earth, Panama typically experiences nine months of precipitation annually. However, 2023's record-breaking lack of rainfall has caused water levels to drop so significantly that it has disrupted global supply chains.

The delays have affected European-based businesses, governments, and communities that depend on goods (e.g. food, pharmaceuticals, machinery, computer chips, humanitarian aid, transport equipment) traversing a well-functioning Panama Canal (Delegation of the European Union to Panama, 2021). While global supply chains are typically robust and built to absorb disruptions, operators of large ports and canals are reevaluating operations and infrastructure to adapt to the new reality of climate change and variability (France24, 2023).

3. THE MULTIPLE VULNERABILITIES OF SUPPLY CHAINS

Europe’s socio-economic systems are highly reliant on international trade and cross-border cooperation. Today, two-thirds of international trade is underpinned by global value chains (OECD, 2022), and the EU’s strong economic growth has been driven by the emergence of more interdependent global supply chains. Supply chain vulnerabilities impact suppliers, infrastructure, and consumers. Regarding infrastructure, impacts can be direct or indirect and their duration spans short, medium, and long-term timeframes (Table 1).

Table 1. Direct and indirect impacts to supply chain infrastructure, generalized.

Direct impacts	Indirect impacts
Primary direct impacts <ul style="list-style-type: none"> ● Physical damage to buildings and infrastructure ● Physical damage to raw materials ● Theft, deliberate destruction, and conflict (i.e. diversions of Ukrainian wheat) ● Physical damage to products in stock ● Physical damage to semi-finished products ● Physical damage to production equipment disruptions ● Physical damage to agricultural land 	Primary indirect impacts <ul style="list-style-type: none"> ● Loss of production due to supply-chain disruption ● Loss of production due to direct damages ● Loss of production due to infrastructure ● Increases in insurance and litigation cost ● Increased costs of goods ● Inflation
Secondary direct impacts <ul style="list-style-type: none"> ● Costs for recovery and reconstruction ● Costs for remediation and emergency measures ● Costs for institutional capacity development and improvements ● Costs of databases and tools ● Costs of research and data analytics 	Secondary indirect impacts <ul style="list-style-type: none"> ● Market disturbances (e.g. price variations of complementary and substitute products or raw materials) ● Damage to company’s image ● Decreased competitiveness ● Increasing productivity and technological development, in the medium and long term ● Increasing affordability crises, poverty and inequality

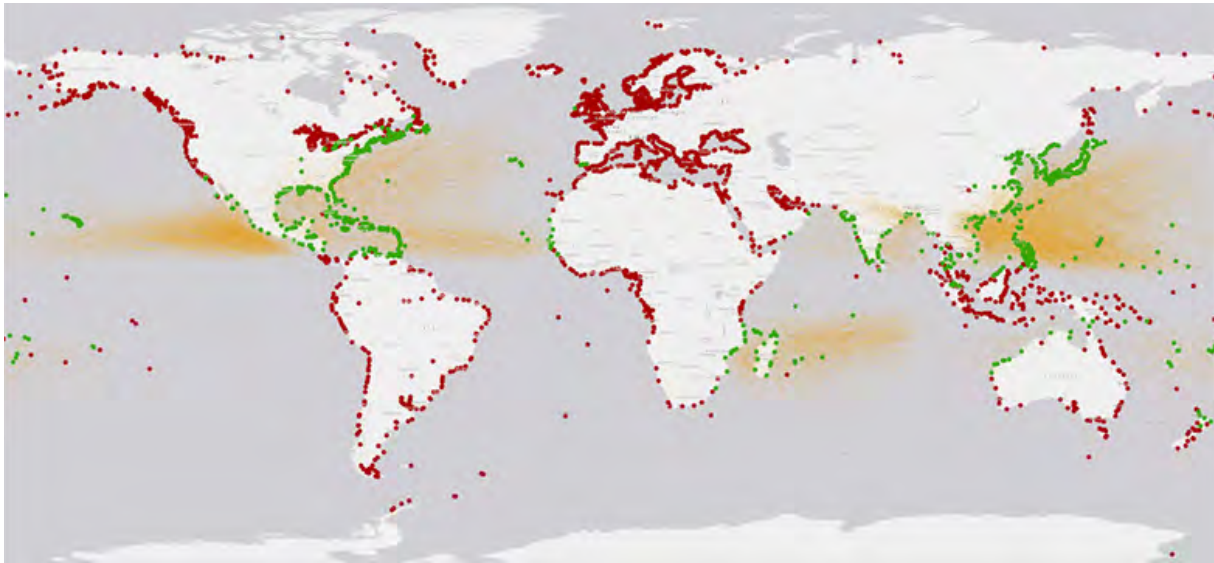
3.1 Leaner supply chains have increased vulnerability

The dynamics of market liberalization and decentralization over the last three decades have redesigned supply chains to become leaner and more efficient. This has enabled greater efficiency across operations and delivered cost reductions, by making them more centralized, specialized, and consolidated. While this streamlining of supply logistics has delivered significant improvements across inventory levels, on-time deliveries, and shorter lead times, these efficiency gains have come at the expense of redundancies that provided buffers against external shocks and disruptions. The absence of buffers has rendered supply chains less resilient and more vulnerable to disruptions from conflict, disasters, operational failures, and climatic risks. The current supply chain configurations and design weaknesses are likely to exacerbate the impacts of climate change on supply chains, unless resilience is integrated into strategies for managing risks to the international trade system and businesses (Komaromi, Cerdeiro, & Liu, 2022).

3.2 Port infrastructure is exposed to new threats

Well-functioning port infrastructure is critical to the EU’s stability, because ports connect importers and exporters across vast networks of waterways and serve as the operational hubs for Europe’s world-class logistics supply chain. Understanding vulnerabilities of ports can help policymakers, investors, and capital holders to visualize and understand where vulnerabilities are so they can better prepare for increased variability and uncertainty resulting from climate change.

Figure 1. Between 1960 and 2016 tropical storms came within 50km of approximately 1100 ports, marked green, out of a total of around 3700 ports, the remainder of which are marked red. Storm tracks are marked orange. Climate change will increase the severity, frequency, and impacts of storms on ports in green.



Source: Becker, et al. Implications of Climate Change for Shipping: Ports and Supply Chains, 2018 https://digitalcommons.uri.edu/cgi/viewcontent.cgi?article=1018&context=maf_facpubs.

Most of the world’s busiest ports regularly experience natural hazard events and about a third of the world’s ports were built and operate in areas exposed to tropical storms (see **Figure 1**). Climate change is expected to amplify the impacts of future coastal hazards. Projected changes include an increase in the frequency and intensity of extreme atmospheric events – shocks such as storms, heavy precipitation, and heatwaves; as well as longer-term changes to climatic variables resulting in slow-onset changes like sea level rise, wave climatology, and sea-surface salinity (leading to higher rates of corrosion). In fact, a recent multi-hazard analysis revealed that 86% of ports globally are already exposed to one or more climatic hazards and 40% are exposed to extreme maritime conditions that could disrupt their operational capabilities. Fluvial and pluvial floodings were found to be the most prevalent hazards, affecting 80.4% and 84.3% of ports, respectively (Verschuur, Koks, Li, & Hall, 2023).

However, these longer-term stresses (rather than shocks) are generally not being factored into port management. Furthermore, climate change impacts affect different places in different ways, and therefore decision makers will need localized (i.e. downscaled) climate scenarios to inform the range of possible climate “futures” for consideration by individual ports and associated supply chains. There is also a growing body of evidence suggesting that land-based and airfreight infrastructure is similarly exposed to climatic hazards (Mikaelsson & Dzebo, 2023).

4. CLIMATE RISK AWARENESS AND PREPAREDNESS AMONG GOVERNMENTS AND BUSINESSES

For several decades trade policies have been underpinned by a free trade and liberal market agenda that devolves governance of critical supply chains to the market. This approach, adopted by governments around the world, is based on the belief that financial institutions and businesses are best positioned to manage risks in isolation without coordination with governments and other businesses. However, recent supply chain shocks caused by the Covid-19 pandemic, the Suez Canal blockage and Russia's war in Ukraine have culminated in a cost-of-living crisis across Europe and called into question the market-first approach. In fact, the exposure of the international trade system and global value chains to both climatic and non-climate risk have begun to command the attention of both governments and businesses.

Discussions at the European Climate Risk and Trade Policy Forum made it clear that some European governments have started to consider using trade policies to enhance the resilience of their countries' supply chains. These policies include:

- diversification, which involves finding alternative sources of supply to reduce dependencies
- stockpiling vulnerable goods to achieve "surge capacity", and onshoring to increase domestic production to manage demand
- innovation or substitution to manage demand, and
- proactive international partnerships and collaboration.

However, efforts by many European governments to identify and implement measures to climate-proof their trade links remain in their infancy. Therefore, it is urgent that those who make trade policy understand the potential socioeconomic impacts of climate change across different sectors in order to assess risk and prioritize and plan effectively (see **Box 2**).

In the wake of recent crises, supply chain disruptions are now ranked among the top risks faced by businesses, second only to the rising costs of raw materials, which are also partly affected by climate

Box 2. Business strategies for climate adaptation in supply chains

Because businesses best understand how their supply chains function and have access to relevant information, they are well placed to take adaptation action to strengthen the resilience of their supply chains. A few frameworks have been developed with the aim to help businesses include climate adaptation in supply chains:

Business for Social Responsibility (BSR) has set out a three-step framework to help companies take action to develop climate resilient supply chains, which consists of 1) identifying priorities, 2) taking action and developing targets, and 3) evaluating impact (BSR, 2015). The report recommends that businesses carry out climate risk assessment or scenario analysis to identify vulnerable points in their supply chains, and then implement adaptation policies to improve resilience, which include strategies and measures that cover internal operations, supplier engagement and collaboration with businesses and social partners.

The UK Committee on Climate Change outlined two main types of action that businesses can take to strengthen the resilience of their supply chains: bridging and buffering (UK Climate Change Committee, 2022). Bridging refers to actions taken by businesses to expand their own capacity and that of their supplier to manage and recover from disruptions, which includes working with suppliers on risk management, and strengthening relationships with them through long-term contracts and financial support. Buffering, on the other hand, involves actions taken by businesses to protect themselves from the consequences of climate disruptions at the supplier level, such as by creating inventory and lead-time buffers, and diversifying the geographical location of suppliers, supply routes and transport modes.

change (Accenture, 2023). Climate change is already impacting the financial performance of businesses and their value chains. A World Economic Forum survey of 100 major businesses reported that the financial impacts from physical climate risks already amount to 10% of annual sales and 4% of their market value (World Economic Forum and PwC, 2023)

Yet businesses have been largely absent in efforts to adapt the global economy to the impacts of climate change. The private sector contributes a mere 3% of all adaptation financing, according to the World Economic Forum (World Economic Forum and PwC, 2023). There is also mounting evidence suggesting that businesses are poorly prepared for rapidly accelerating risks of disruption to their operations and supply chains. According to a recent study in the Harvard Business Review, only 11% of suppliers (i.e. original equipment manufacturers) in the US, China, and Taiwan are fully prepared for even typical and predictable weather disruptions, even though 49% of suppliers based in the US and 93% of suppliers in China and Taiwan said they have experienced an increase in climate volatility (Boyson, et al., 2022).

These findings are in line with recent surveys showing that relatively few supply chain leaders of major companies have conducted assessments of climate risks to their supply chains, and only a small minority have plans to implement adaptation measures (Gartner, 2022; Laidlaw, Bowles, & Beckwith, 2023). Such findings suggest that businesses lack a comprehensive understanding of the climate risks posed to their supply chains, and thus are likely to miss out on investment opportunities that could increase their resilience and bottom lines.

Because different climate hazards affect supply chains differently, there is a need for a broad array of adaptation solutions. While some supply chains can benefit from diversification and substitution, others depend on raw materials that cannot be substituted or diversified because they rely on production locations with specific climatic and geological properties. Still, there are opportunities and incentives for businesses within sectors to work together to share risk information and invest in adaptation for shared supply chains. However, the agility of individual businesses and their approach to risk are key determinants of their operational resilience. Businesses that look beyond risk probabilities to explore broader sets of plausible scenarios (including tail-risks) so that they can examine their tolerance to major supply chain disruptions are more likely to be prepared to withstand and recover from shocks when they occur.

5. BARRIERS TO BUSINESS-LED CLIMATE ADAPTATION IN SUPPLY CHAINS

The private sector consultations linked to the European Climate Risk and Trade Programme, the UN Global Compact Think Lab and the World Economic Forum suggest that a wide range of factors are behind the slow progress of European businesses on climate adaptation. Many of these factors relate to internal corporate constraints and risk culture, whereas other factors relate to broader market challenges. In some cases, climate risks are simply not on the radar of the businesses, even among some multinational corporates, because they perceive the physical impacts of climate change as immaterial to their business operations in the near term. In other cases, businesses do not have access to relevant data and information on climate risk and adaptation, which makes it difficult for them to put value on the benefits of adaptation and the costs of inaction, and ultimately to build the case for investment. The recent crises stemming from the Covid-19 pandemic, the Suez Canal blockage, and Russia's war in Ukraine have also taken a serious toll on businesses and kept many in survival mode for a sustained period, placing serious constraints on their capacity to prepare and plan for future crises.

The degree of influence that European businesses have on their supply chains can vary considerably depending on the size of businesses, geography, which sector they operate in, and what product or service they offer. Because many suppliers favour partnerships with larger businesses, which offer bigger and more secure long-term demand for their products and services, multinational corporates are well-positioned to leverage their influence to encourage and support their partners in identifying their climate risk exposure and to take adaptation action. However, large multinational corporations often rely on a complex web of supply networks that include hundreds or thousands of different suppliers across multiple tiers, which can seriously limit the oversight and influence that such corporations have over their suppliers.

Larger businesses often suffer from atomized operational structures, which prevent coordinated risk management.

Larger businesses often suffer from atomized operational structures, which result in institutional siloes and inertia that prevent an effective and coordinated response in risk management, procurement, and sustainability teams. That said, strong corporate leadership at board or executive level could help ensure internal alignment and drive an effective adaptation strategy across entire corporate structures. However, small and medium-sized enterprises (SMEs), which themselves are often suppliers to other businesses, may simply not have the human capital or financial resources to conduct climate risk assessments or implement adaptation measures, because they are likely to have weaker balance sheets and less access to finance compared to larger businesses (Mikaelsson, Dzebo, & Klein, 2023). This highlights the importance of adopting more nuanced approaches when addressing the challenges of climate risk to businesses and barriers to adaptation between businesses of different scales.

5.1 Data-driven decision making

To reduce the economic costs of climate change it is essential to better understand global supply chains and reliably identify the most vulnerable entities (e.g. key production hubs and critical transport and energy infrastructure). To do so, there is a pressing need for better data. In particular, there is growing demand for:

- supply chain traceability
- multiple risk profiles, and
- tools and data for visualizing supply chains.

European decision makers and their trading partners will need to understand how to use new supply chain analytics, combined with climate information and other risk data, to design well-informed plans to reduce and manage risks to supply chains. Decision makers will also need reliable tools to analyse the intra-regional and intra-sectoral links between trade demand and infrastructure status. While there are some international databases that capture the trade relationships between countries and sectors (see **Table 2**), they make only limited use of climate information and other risk data models, which makes it difficult to: a) comprehend and leverage data for short, medium, and long-term planning, and b) estimate the wide range of cascading effects resulting from disruptions along international supply chains.

Table 2. Examples of public supply chain databases

Database	URL
EU Supply Chain Viewer, via the EU Joint Research Centre	https://data.europa.eu/data/datasets/496f1938-7c7b-4173-b504-79542467a390?locale=en
Supply Chain Visualization and Analysis, via Esri ArcGIS	https://www.esri.com/en-us/industries/manufacturing/strategies/supply-chain-distribution
EU Raw Materials Information System (RMIS), via the European Cluster Collaboration Platform	https://rmis.jrc.ec.europa.eu/

In addition to the need to increase capacity to utilize tools and data, decision makers will be required to monitor emerging trends and events along major transport routes and nodes (e.g. the Panama Canal, Port of Singapore, Port of Rotterdam, etc.), as well as in source producer countries (e.g. conflict, disasters, political shifts, new trade agreements). Again, the data gaps and lack of tools that cover these issues contribute to a context of low information and large uncertainty, which means it is very difficult for the EU to estimate and manage economic costs. However, EU decision makers can incentivize research institutions and private entities to invest in tools and information services. The results should lead to a clearer understanding of the risks to supply chains from both acute and slow onset climate change, which is fundamental for planning effective adaptation and risk management strategies.

6. HOW CAN GOVERNMENT POLICY ACCELERATE BUSINESS-LED ADAPTATION?

European businesses are not only exposed to risks from the many physical climate impacts that can disrupt their own supply chains (see Figure 1), but also from disruptions of other supply chains that can reduce availability and increase costs of key raw materials. The lack of progress on business-led adaptation is therefore a major concern for EU and European countries. It also underlines the need for governments to boost the resilience of supply chains to minimize the effects of shocks and disruption and safeguard the provision of food and other essential materials and products. A failure to climate-proof Europe's supply chains will jeopardize food security, healthcare systems and business operations across the continent, as well as put at risk the health, safety and livelihoods of the workers and communities that underpin them.

In the private sector consultations we draw on in this paper, many European businesses were critical of inadequate government support, and identified the lack of an enabling environment as a major barrier to business action on adaptation. It requires substantial capital for businesses to deliver the bold and transformative changes in operations and practice that are needed to deliver climate-resilient supply chains, which can result in higher operational costs that can harm competitiveness and send harmful market signals (Mikaelsson, Dzebo, & Klein, 2023). Businesses have therefore called on governments to introduce both legislative and market instruments to level the playing field for companies that want to take bolder and more transformative action. Businesses have suggested several measures that governments could take to overcome barriers and drive meaningful impact on business-led adaptation.

For example, governments could introduce stronger statutory requirements and robust enforcement for the disclosure of physical climate risk exposure, as well as implement adaptation measures to manage these risks. The EU Corporate Sustainability Due Diligence Directive was recently introduced to encourage larger businesses to carefully manage their impacts and that of their supply chains on the environment and human rights; clauses on climate adaptation could be introduced into this legislative framework.

Because SMEs play an important role in global supply chains, but often lack the know-how, capacity, and financial resources to invest in climate adaptation, governments could work with larger businesses, industry associations and social partners to provide technical support and access to finance to help smaller suppliers conduct climate risk assessments and implement adaptation solutions. For example, governments could provide non-competitive funding, and/or introduce tax-related subsidies, for SMEs to adopt more climate resilient practices and invest in climate-proofing their infrastructure.

Finally, governments and other public authorities could also design public procurement systems to ensure that public sector supply chains are resilient, and thus demonstrate willingness to pay a premium for more climate-secure supplies. In fact, a key recommendation of the UK Committee on Climate Change was that public authorities should develop appropriate metrics and targets on climate adaptation, and incorporate them into tender criteria and minimum standards to encourage suppliers to adopt and invest in measures for climate resilient supply chains (UK Climate Change Committee, 2022).

7. CASE STUDY: RISKS TO CRITICAL PHARMACEUTICAL SUPPLY CHAINS IN THE EU AND POTENTIAL SOLUTIONS

Despite its overall economic strength and relative resilience, the EU is increasingly at risk to climate-sensitive infectious diseases, which will affect people working in agriculture, forestry, and emergency services, as well as the elderly, children, and those with compromised immune systems (see Table 3). Higher temperatures increase the risk of West Nile fever outbreaks and wider distribution of mosquito species that act as vectors for malaria and dengue, while warming sea waters will be habitat for the dangerous *Vibrio* bacteria. Higher volumes of treatments, drugs and vaccines will be required as climate changes, and floods, extreme heat, major storms, issues with ports and canals, and political strife all affect various nodes and entities along supply chains. Pharmaceutical logistics providers must ensure that drug shipments reach their destination in their intended condition without defect or delay.

Managing pharmaceutical supply chains is complex and challenging, and even more so during widespread disease outbreaks.² Many pharmaceutical companies operate with only one site available to produce each product, due to the high costs of facilities, regulations, local labour capabilities, and demand. On-time deliveries are vital for pharmaceuticals, and temperature-controlled transport and storage facilities must be successfully managed with product-specific compliance, as well as the delivery of medicines and materials to the right place in the right condition. Pharmaceutical companies have a responsibility and a business imperative to adapt their processes and keep their supply lines open and accessible. Additionally, EU decision makers are under immense pressure to equitably and efficiently deliver life-saving medicines that are vital to patients. Thus, the EU increasingly requires reliable, nimble, and responsive pharmaceutical supply chains.

Governments and businesses each play a vital role in ensuring the safe and efficient delivery of vaccines and maintaining the integrity of vaccine supply chains. **Table 3** demonstrates several weaknesses in these chains. In addition, limited redundancy in vaccine supply chains equates to high vulnerability and multiple threat pathways. When climate risks are included in the picture, their vulnerability increase still further. Collaboration and coordination among these stakeholders are essential to address the challenges associated with each element of the supply chain.

Table 3. Multiple challenges to EU pharmaceutical supply chains

Sources	Challenges
<p>Manufacturing and production</p> <p>This stage involves the production of vaccines in controlled environments. It includes cell culture, purification, formulation, and fill-finish operations.</p> <p>Managed by pharmaceutical companies, biotechnology firms, and contract manufacturing organizations.</p>	<p>Ensuring the consistent quality of vaccines, adhering to good manufacturing practices, and managing the complex production process with strict requirements for sterility and purity.</p>
<p>Packaging</p> <p>Vaccines are typically packaged in glass vials or pre-filled syringes, often with specialized labels or indicators to monitor temperature and tampering.</p> <p>Managed by packaging manufacturers, pharmaceutical companies, contract packaging organizations.</p>	<p>Designing packaging materials to maintain vaccine integrity, protecting against light exposure, moisture, and physical damage, and ensuring tamper-evident seals.</p>

2 Because pharmaceutical supply chains are highly complex, this example leaves out many aspects of the chain, such as safety, government reporting, patenting, theft, tracking, labeling, testing, disposal, spoilage, various types of insurance, crime elements, and other regulatory issues.

Sources	Challenges
<p>Specialized storage facilities</p> <p>Refrigerators, freezers, and ultra-low temperature freezers are used to maintain vaccines at precise temperature ranges.</p> <p>Managed by healthcare facilities (hospitals, clinics, pharmacies), pharmaceutical distribution centres, vaccine manufacturers.</p>	<p>Consistently maintaining temperature control within specified ranges, having back-up power systems, and monitoring conditions with data loggers. Equipment failure or power outages can lead to vaccine spoilage.</p>
<p>Ground transport</p> <p>Vaccines are transported via refrigerated trucks or vans equipped with temperature-controlled units.</p> <p>Managed by logistics companies, cold chain transport providers, freight carriers, third-party logistics (3PL) providers.</p>	<p>Maintaining the cold chain during ground transport despite challenges like traffic delays, accidents, and mechanical breakdowns. Specialized training for drivers and regular equipment maintenance are essential.</p>
<p>Air transport</p> <p>Vaccines can be transported by cargo planes or specialized containers.</p> <p>Managed by air cargo carriers, airlines with specialized cargo divisions, airfreight forwarders.</p>	<p>Ensuring consistent temperature control during loading, unloading, customs checks, and the flight itself. Adhering to international regulations for hazardous materials and ensuring cargo compatibility with aircraft systems.</p>
<p>Sea transport</p> <p>Vaccines can be shipped in refrigerated containers on cargo ships.</p> <p>Managed by shipping companies, maritime logistics providers, container shipping lines.</p>	<p>Navigating long transit times, varying weather conditions, and potential temperature fluctuations. Reliable refrigeration systems on ships and efficient port facilities are necessary for uninterrupted cold chain integrity.</p>
<p>Distribution networks</p> <p>A network of distribution points, including central depots, hospitals, clinics, and pharmacies, is established to distribute vaccines.</p> <p>Managed by pharmaceutical wholesalers, government health agencies, healthcare supply chain companies, distributors, and chain partners.</p>	<p>Ensuring that each distribution point has the necessary storage infrastructure, trained staff, and inventory management systems. Coordination to minimize stock-outs and waste is crucial.</p>
<p>Last-mile delivery</p> <p>The final step of vaccine delivery to end users often involving transport over short distances.</p> <p>Managed by local healthcare providers, courier services, government health workers, non-profit organizations (e.g. UNICEF).</p>	<p>Maintaining temperature control during last-mile delivery, especially in remote areas. Timely access to vaccines for all communities, even those with limited infrastructure, is essential.</p>
<p>Monitoring and data management</p> <p>Continuous monitoring of temperature, location, and shipment conditions using sensors and data loggers.</p> <p>Managed by technology providers (manufacturers of data loggers and sensors), supply chain visibility software companies, logistics companies, government health agencies.</p>	<p>Ensuring real-time visibility and data sharing among all stakeholders, addressing data security concerns, and developing robust analytics to detect and respond to temperature excursions or other issues.</p>
<p>Security and counterfeit prevention</p> <p>Managed by security services providers, regulatory authorities, pharmaceutical companies (for anti-counterfeit measures), customs and border protection agencies.</p>	<p>Implementing security measures to protect vaccines from theft, tampering, or diversion.</p> <p>Employing anti-counterfeit technologies such as holograms or serialized barcodes to prevent the entry of counterfeit products into the supply chain.</p>

8. SHARED RESILIENCE VERSUS MALADAPTATION

Climate risk and vulnerability among suppliers, workers and communities can either be reduced through shared resilience or exacerbated through maladaptation. Maladaptation can stem from misguided actions by businesses that result in labour and social risks, and often happens when businesses fail to properly engage with their suppliers, workers and local communities in their responses to climate risks (Mikaelsson, Dzebo, & Klein, 2023). For instance, some businesses make the strategic decision to abandon or divest from vulnerable markets or markets that are exposed to climate risks

Adaptation measures that help address vulnerability and inequity in communities involved in supply chains are also beneficial for businesses themselves.

(Pankratz & Schiller, 2022), but such actions can undermine people's livelihoods and reduce their resilience – thereby increasing their vulnerability and thus resulting in greater climate risk overall (Dzebo, Lager, & Klein, 2022). Other resilience measures could result in less favourable market access for agricultural and other commodity producers in these vulnerable countries by, for example, forcing suppliers to pay additional risk premiums, which could increase operational costs for suppliers. Higher operational costs could render adaptation measures economically unvi-

able for suppliers and even further exacerbate their vulnerabilities through worsened working conditions, leading to increased climate risk for other businesses that rely on these suppliers.

On the other hand, businesses that place human rights and other values at the centre of how they manage climate risk can capitalize on the synergies between their climate and social objectives and take measures that are mutually reinforcing. For example, if businesses in the agricultural sector paid smallholder farmers a fair and sufficient amount for their products, they would be able to invest in more expensive drought-resistant seeds. In fact, some larger multinational corporates have begun to acknowledge the importance of human capital because there are mutual gains to be made by investing in adaptation measures that go beyond protecting material assets and provide wider benefits to workers and their communities throughout supply chains (Mikaelsson, Dzebo, & Klein, 2023). For instance, adaptation measures that help address vulnerability and inequity in communities involved in supply chains are also beneficial for businesses themselves, because they help maintain business continuity and support productivity. Similar links are emerging between sustainability and resilience in supply chains, as recent evidence suggests that supply chains that are more sustainable tend to also be more resilient (Eggert & Hartmann, 2023). Businesses that carry out materiality assessments and engage with their suppliers on physical climate risks would benefit from greater transparency across their supply chains. This would enable businesses to proactively identify hotspots for risks and challenges that could increase operational costs and delays and take appropriate action.

9. DISCUSSION

Several key vulnerabilities within Europe's supply chains have been identified, with significant implications for policymakers and businesses alike. Europe's socio-economic systems have grown increasingly reliant on global supply chains; EU members account for 16% of world imports and exports. While this interdependence between Europe and the rest of the world has driven relatively stable economic growth, it has also heightened the region's vulnerability to external shocks. These vulnerabilities manifest in both direct and indirect impacts on supply chains, encompassing increased costs and risks from physical damage, and weakened infrastructure, as well as production losses, increased costs, and market disturbances. As noted, these consequences span short, medium, and long time frames, exacerbating the complexity of supply chain disruptions.

Furthermore, the pursuit of efficiency through streamlined supply chains has rendered them less resilient, reducing redundancies in favour of cost savings. This efficiency gain has come at an expense as supply chains are now more susceptible to shocks stemming from conflicts, disasters, operational failures, and climate change impacts. In particular, port infrastructures, vital to Europe's logistics supply chain, face new threats due to climate change. A substantial portion of the world's busiest ports already experience natural hazards, and climate change is anticipated to amplify these impacts, including the frequency and intensity of extreme weather events. The result is a heightened risk to operational capabilities, posing a significant challenge to supply chain stability. At the same time, recent supply chain shocks, such as the COVID-19 pandemic, the Suez Canal blockage, and geopolitical tensions, have forced a reevaluation of the prevailing "market-first" approach to trade policies. However, policymakers urgently require a deeper understanding of the socioeconomic impacts of climate change across various sectors to prioritize their actions effectively, recognizing that not all supply chain disruptions are equally tolerable.

Businesses lack a comprehensive understanding of the risks posed by climate impacts on supply chains, which leaves them vulnerable.

Governments are increasingly recognizing the need to enhance supply chain resilience, with strategies that include diversification of supply sources, stockpiling, onshoring, and new international collaborations. However, these strategies largely fail to account for the systemic risks of climate change and thus fall short of managing compounding and cascading impacts. Diversification of supply chains might prove a robust measure to enhance supply chain resilience in the face of non-climatic risk drivers, such as local disease outbreaks or isolated conflicts, but such measures would be less effective in managing the systemic impacts of climate change, as they are increasingly unfolding through multiple simultaneous extreme weather events around the world. Diversifying sources of supply may not be a sustainable strategy in the long-term; it will become increasingly difficult to determine the resilience of production locations as the impacts of climate change cascade ever further.

Efforts by European governments to onshore supply chains might reduce Europe's exposure to trans-boundary climate risk, but by the same token it would increase its exposure to climate risks within Europe and may even exacerbate risks for others. For instance, onshoring water-intensive agriculture and pharmaceutical manufacturing to southern Europe could exacerbate existing water-stress already aggravated by climate change. Ultimately, it is important to recognize that while Europe's trade links are significant conduits of climate risk, international trade and access to global supply chains can equally play a critical role in strengthening climate resilience by enabling countries to hedge against climate risks for individual sources of supply.

Moreover, the private sector plays a pivotal role in shaping supply chain resilience, as businesses are well-positioned to implement adaptation measures. Unfortunately, evidence suggests that many businesses are unprepared for the growing risk of climate-related disruptions. Only a fraction of businesses have conducted climate risk assessments; fewer have plans in place to implement adaptation measures. Businesses lack a comprehensive understanding of the risks posed by climate impacts on supply chains, which leaves them vulnerable, potentially missing out on investment opportunities to bolster their resilience and financial stability.

Addressing these vulnerabilities demands a multifaceted approach. Policymakers should incentivize research institutions and private entities to invest in tools and information services that enhance risk assessment and planning. They must also foster collaboration and information sharing among supply chain partners, promoting transparency and resilience-building efforts. Furthermore, decision makers must recognize the imperative of integrating climate information and other risk data into supply chain analytics, enabling data-driven decision-making for both short- and long-term planning.

Several collaborative solutions are outlined here, in Section 10 below.

Ultimately, the failure to climate-proof Europe’s supply chains endangers food security, healthcare, and business operations. This is true within Europe, but the well-being of workers and communities worldwide will also be affected. Policymakers and businesses must work in concert to navigate the intricate challenges posed by climate change and ensure the stability and sustainability of supply chains in the region.

10. COLLABORATIVE SOLUTIONS

The EU and Member State governments will need to deploy a range of policy solutions to address weaknesses in supply chains, especially those of high and strategic importance for Europe, such as agri-food products, pharmaceuticals, and critical raw materials. While policies will often require a sectoral approach tailored to the specific attributes and demands of a given supply chain, governments must also design broader strategies and policies that can enhance climate resilience in European trade across sectors. To do so, there is a need to improve collaboration between governments and among businesses, and to strengthen public-private partnerships. Below we set out some recommendations, which draw on consultations with private sector stakeholders.

1. A central recommendation is that the EU and Member States work closely with the Joint Research Centre of the European Commission, the European Environment Agency (EEA), and EU financial institutions such as the European Central Bank (ECB), European Investment Bank (EIB) and the European Bank for Reconstruction and Development (EBRD), to conduct climate risk assessments and scenario analyses – incorporating both deterministic and stochastic scenarios. These would provide a better understanding of existing and future vulnerabilities of the EU’s critical supply chains to physical climate impacts.

Collaboration between public institutions and private entities will be needed to synthesise the most up-to-date and accurate datasets needed to conduct meaningful assessments of supply chain risks in a changing climate. These data can be used to inform government climate and trade policies, and to help accelerate adaptation planning in the private sector.

2. The EU and Member States should work together to introduce mandatory disclosure requirements on physical climate risks and adaptation implementation for larger corporations and infrastructure providers and utilities, supported by appropriate adaptation metrics.

Instead of establishing a new bespoke disclosure framework for physical climate risks, new adaptation-related clauses could be embedded into the EU Supply Chain Directive and existing disclosure requirements of EU financial institutions. A robust and effective enforcement mechanism is needed to ensure that companies are transparent about risks and are held accountable for disclosing climate risks. This would help to create a regulatory framework that incentivizes better climate risk assessment and adaptation in the private sector.

3. European governments should assemble a joint task force, drawn from the private and public sectors, to develop platforms for sharing risk data and encourage co-investment in adaptation. The task force should place particular emphasis on facilitating partnerships among companies that share supply chains infrastructure and it should support SMEs. The task force should develop recommendations for business that are both cross sector and sector specific, in collaboration with key industry actors and with strong engagement from SMEs.

4. The EU and its Member States should work together to design and implement policy actions to incentivize public and private investment into adaptation, in consultation with early adopters in the business community and the financial sector. Regulatory bodies can develop, for example, tax incentives, streamlined permitting, special designation and certification, which would stimulate finance and funding to strengthen the climate resilience of supply chain infrastructure. Lengthy and complex permitting, and approval processes often hinder standard development of infrastructure in critical supply chains. The EU and regulatory bodies could simplify and expedite permit and approval procedures, ensuring they are efficient, transparent, and include requirements for climate adaptation.

European authorities should also leverage the purchasing power of public procurement to send a strong market signal for climate resilient supply chains. Public authorities at EU, national and

sub-national levels should incorporate specific criteria and minimum standards for climate adaptation, to influence suppliers across the different tiers of the supply chain. Public funding agencies should significantly increase the availability of adaptation finance for European SMEs and other key infrastructure operators.

By providing incentives for climate-resilient infrastructure, European governments can enhance the reliability, resilience, and preparedness of supply chains of both critical and everyday goods, while a streamlined approach could accelerate identification of, and investments in critical supply chain infrastructure for the EU.

To ensure robust and climate-resilient supply chains, and the continuous flow of critical goods and services even in the face of climate-related challenges, it is particularly important to develop a stable regulatory environment that integrates climate adaptation considerations, investor-friendly policies with climate resilience incentives, and streamlined permitting processes with climate risk mitigation strategies.

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Adaptation Without Borders is a global partnership working to strengthen systemic resilience to the cross-border impacts of climate change. We identify and assess transboundary climate risks, appraise the options to better manage those risks and support policymakers, planners and the private sector to develop climate-resilient and inclusive solutions. We catalyse new alliances and forms of cooperation on adaptation that pave the way towards a more sustainable and resilient world.

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