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TOWARDS UK SYSTEMIC RESILIENCE TO INTERNATIONAL CASCADING CLIMATE RISKS

The Role of Infrastructure and Supply Chains

This report was developed by

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Foreign, Commonwealth & Development Office

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CONTENTS

ABBREVIATIONS

ACRONYMS	DEFINITIONS
ADB	Asian Development Bank
AfDB	African Development Bank Group
AllianzGI	Allianz Global Investors
ARCH	Cold Chain Solutions East Africa Fund
BIP	British Investment Partnerships
CAW	African Development Fund's Climate Action Window
CCC	Climate Change Committee
CCRA	Climate Change Risk Assessments
CDRI	Coalition for Disaster Resilient Infrastructure
CIV	Collective Investment Vehicle
CRDC	Climate Resilience Debt Clauses
DF	Development Fund
DFI	Development Financial Institution
EIB	European Investment Bank
EMCAF	Emerging Markets Climate Action Fund
EMDEs	Emerging and developing economies
ESG	Environmental, Social and Governance
ESG	Environmental, social and governance
ESMS	Environmental and Social Management System
EU	European Union
FDI	Foreign Direct Investment
FTA	Free Trade Agreement
GIRI	Global Infrastructure Resilience Index

GIS	Geographic information system
ICF	International Climate Finance
LMIC	Low- and Middle-Income Countries
MDB	Multilateral Development Bank
MOBILIST	Mobilising Institutional Capital Through Listed Product Structures
NGFS	Network of Central Banks and Supervisors for Greening the Financial System
NGO	Non-Governmental Organisation
ODA	Official Development Aid
OECD	Organisation for Economic Co-operation and Development
OxMarTrans	Oxford Maritime Transport model
PIDG	Private Infrastructure Development Group
SDGs	UN Sustainable Development Goals
SFDR	EU Sustainable Finance Disclosure Regulation
SitCen	National Situation Centre
SME	Small and Medium-sized Enterprise
SPEM	Spatial price equilibrium model
TCRs	Transnational Climate Risks
UKRF	UK Resilience Forum
UN	United Nations
UNDRR	United Nations Office for Disaster Risk Reduction
UNEP	UN Environmental Programme
USD	US dollars
WEF	World Economic Forum

EXECUTIVE SUMMARY

The UK's security and prosperity are powered by many complex global supply chains – including food, critical minerals and manufactured products – and thrive in a stable global macroeconomic and geopolitical environment. Climate change, biodiversity loss and environmental degradation will radically reshape the landscape of risks and opportunities faced by the UK. The third UK Climate Change Risk Assessment recognises these 'international dimensions' of risk and highlights the potential 'high' risk of 'systemic risk arising from the amplification of named risks cascading across sectors and borders' (ID10) and medium to high risks related to international food supply chains, finance and international trade routes.

This report considers the specific role of infrastructure and supply chains in these global systemic risks related to climate change, and how investing in resilient infrastructure and nature capital can help to mitigate the impacts. The supply and transport of food, manufactured products and critical minerals, for example, are dependent on physical infrastructure (ports, airports, roads, electricity) as well as numerous types of so-called green infrastructure (natural capital). Wider global economic development is also dependent on robust and adequate infrastructure systems, and infrastructure influences all 17 of the SDGs, either directly or indirectly – including 72% of the underlying SDG targets. Yet this infrastructure is highly vulnerable to climate impacts, as supplies remain dependent on a range of natural systems, and the risks of interruption are increasing over time. Our financial institutions, including insurers and investors, are directly and indirectly exposed to these risks.

In this context, the research summarised in this report has two mutually reinforcing objectives:

- To build the evidence case for how investments in resilient infrastructure and natural capital in EMDEs can strengthen UK systemic resilience to climate related shocks.
- Strengthen knowledge on how the UK, through its foreign policies and development financing, can help close the resilience gap for infrastructure in EMDEs.

This research was supported by the Foreign, Commonwealth and Development Office (FCDO) and leverages ongoing research by the Oxford Martin Systemic Resilience Initiative. The project was delivered in collaboration with Chatham House and convened experts from across policy, development finance, infrastructure investment and CSOs to develop recommendations for how the UK's development and foreign policy toolkit can help close the resilient infrastructure gap, including through international standards, financial regulation and supervision, the role of international financial institutions and investments in public goods, such as data.

A key finding of this study is that without action, growing infrastructure and trade-related risks could undermine the UK's systemic resilience, putting critical systems and supply chains at risk. We review growing risks related to international supply chains, with a focus on food, fuel and critical minerals, as well as direct risks to infrastructure, transportation routes (ports, airports, roads, rail) and natural capital. This includes both model-based evidence and evidence of materiality of risks from recent events, such as disruption to the Panama Canal. For example, we report evidence that well over $60 billion worth of trade is at risk annually from climate-related shocks, with high trade risk being concentrated in East Asian ports, prone to tropical cyclones and the concomitant port downtime. Our research also shows that risks related to the loss of natural capital act as a risk multiplier on climate risks and could lead to trillions of USD in losses from risks related to water, soil health and pollution. The study then provides new analyses focussed on four case studies:

- **Ports:** The UK, like many other countries, is exposed to supply chain risks related to port disruption. In total, the climate-related financial losses to UK trade (because of port disruptions) are estimated to be around $2.5 billion per year. The key ports driving these risks are located in the USA, South Korea and East and South-East Asia.

- **Food:** Weather variability alone can cause price fluctuations of UK grain prices, but only within 10–15%. However, climate-related shocks combined with other factors can lead to much larger volatility in prices. The UK grain supply system does have some existing levels of resilience through supply diversification and strategic supply dependencies. However, the UK grain supply network remains vulnerable to breadbasket failures.
- **Natural capital**: Nature-related risks are financially material to the UK economy and financial sector, and at least half of these risks are related to international supply chains. Under a scenario of a major international supply chain shock related to natural capital degradation globally, the UK could incur losses of at least 6% of GDP relative to baseline growth within the next decade.
- **Energy (green ammonia):** Green ammonia could be considered an option in the long-term to improve the resilience of the UK energy system under high penetration of renewable energy, which is expected to take place by 2035. Unlike for fossil fuels, sources of green ammonia are likely to be spread across many countries, making diversification easier. The top 30 countries for future production potential are all concentrated in Africa and include countries with ongoing fragility and currently unfavourable investment climates. For policy makers, this raises questions about how to engage over the next decades to secure stable supply chains of green ammonia for the UK.

Based on this review and new analyses, we conclude that the nature of these emerging risks is different from what has been experienced in the past, and this will bring new challenges for risk management. This includes:

- **Potential for abrupt shifts**: Rising risks associated with the erosion of natural assets and ecosystem services, including the potential to reach local ecological tipping points that could lead to abrupt and severe impacts on global supply chains.
- **Evolving dependencies and risks**: Our evolving domestic energy and food systems, trade relationships, and the shifting patterns of production and consumption globally, will change patterns of dependence on overseas partners. For example, there may be a shift away from dependence on oil-producing countries and towards new suppliers of critical minerals and green ammonia, including countries across Africa.
- **Increasing exposure to global cascading and complex risks** due to the more interconnected and interdependent nature of our economy.
- **Increased risk of highly correlated shocks across countries and sectors:** Compounding climate and nature-related risks, leading to systemic-level impacts across countries and sectors that could severely disrupt the global economy.
- **'Polycrises'**: Increasing chance of being affected by more than one event simultaneously, with compounding consequences leading to more severe impacts.

Managing such transnational climate risks (TCRs) will require action at multiple levels, from local to global. In this report, we conduct a preliminary assessment of current UK policies related to TCRs and discuss policy implications in five key areas: finance and investment; data; trade and supply chains; corporate and financial regulation; and global risk governance. On infrastructure and natural capital finance and investment, we focus on understanding the barriers to investment and the role of development interventions, including blended finance. From this, we draw four novel recommendations to mobilise more finance and action to address TCRs:

1. **Universal asset owners/large institutional investors** are better able to internalise the positive externalities from their investments in resilient infrastructure globally. These large investors benefit from the reduced risks to other parts of their portfolios both directly and directly. Action by institutional investors could be encouraged through regulatory and supervisory requirements to assess and disclose risks and to fully capture risks within capital allocations and pricing.

2. **Regulatory or policy interventions** that require resilience standards on systemically important infrastructure or allow the externality to be internalised, e.g. through a tax benefit or subsidy for investing in resilience.

3. **Smart credit ratings**. Infrastructure investments do not yet yield additional compensation in terms of higher credit ratings; this could be addressed by increasing transparency in ratings.

4. **Concessional finance for systemically important infrastructure.** There is a case for public investment – including in the form of blended finance – to ensure the resilience of systemically important infrastructure and correct the market failure.

We also draw out important recommendations in wider areas, in particular the importance of embedding TCRs (climate and nature) explicitly within corporate and financial regulation, and the need and opportunity to catalyse action through providing data as a public good. For example, we conclude that the lack of data and the fact that TCRs are not included in the current scenario exercises of central banks are leading to a lack of preparedness for these risks across the economy and financial sector, and consequently, a lack of investment.

In summary, a clear conclusion of the study is that investing in resilient infrastructure and natural capital globally benefits both the UK and developing countries. Of the trillions of pounds in investment required annually to mitigate and adapt to climate change and achieve the Sustainable Development Goals (SDGs), most will be needed for infrastructure and for protecting and restoring natural capital in EMDEs. Investment here can yield immediate benefits, both locally in terms of improving development outcomes, and globally by ensuring resilient food, energy, transport and natural systems. The current shortfall in investment has implications for both EMDEs and the UK's security and prosperity.

1. INTRODUCTION

The UK's security and prosperity are powered by many complex global supply chains, including food, critical minerals and manufactured products, which depend on a wide range of grey and green infrastructure. The UK's third Climate Change Risk Assessment (CCRA3) recognised that climate risks to international supply chains constitute a high risk to the UK economy and also a risk that is not well understood. This study focusses on the role of grey and green infrastructure in mitigating climate risks and on the opportunities to reduce risks to the UK economy through investing in resilient infrastructure and natural capital.

The supply and transport of goods are often dependent on physical (or 'grey') infrastructure (ports, airports, roads, electricity) and underpinned by numerous types of green infrastructure or natural capital, in particular water, fertile soils and other critical ecosystem services. This grey and green infrastructure is highly vulnerable to climate variability and extreme weather. Moreover, critical supply chains are dependent on a range of natural systems that are currently under threat from land-use change, overextraction and pollution, as well as climate change. These pressures on nature from human activity escalate the risk of reaching ecosystem tipping points: 'non-linear, self-amplifying and irreversible changes in ecosystem states that can occur rapidly and on a large scale' (Marsden et al. 2024).

Previous studies have shown that increasing interruptions in international trade and supply chains can create significant risks to the UK's economy and people, underlining the need for substantial investments in building systemic resilience globally and nationally. CCRA3 estimates that if the international climate risks to the UK are not acted upon, this could cost the country over £1 billion annually from 2050 onwards (Climate Change Committee 2021). Infrastructure investments constitute a key component of efforts towards strengthened resilience. The Coalition for Disaster Resilient Infrastructure (CDRI) highlights that 'having capability to prevent and to prepare for infrastructural failures, and thus to manage infrastructural interdependencies, is seen as a major prerequisite for resilient societies' (Kannan et al. 2021). Yet, the rapid evaluation of progress against the UK adaptation actions completed by the Climate Change Committee in March 2024 found that only just over a quarter of those actions identified in CCRA3 to adapt to the international dimensions of climate change risks had been fully or significantly addressed, and a third had not been addressed at all (CCC 2024).

This study explores the international risks of climate and environmental changes to the UK's systemic resilience and the potential solutions, through the twin lenses of infrastructure and nature capital. We define systemic resilience as 'the dynamic capacity of the integrated system to minimize the tails of the damage distribution and to prevent a total failure or collapse over time.' In reference to global infrastructure systems more specifically, we understand systemic resilience as the capacity of infrastructures 'to provide altogether trustworthy operations in hostile environments/ degraded mode (systemic robustness) and to quickly regain (systemic recovery speed) an optimal level of functioning' (UNDRR 2022a, 4).[1]

1 Resilient infrastructure systems have also been conceptualised as sufficiently robust with sufficient redundancy, allowing for 'sufficient resourcefulness to resolve issues with sufficient rapidity to continue operating at normal or near normal performance levels' (Gallego-Lopez and Essex 2016, 8)

The study was commissioned by the Foreign, Commonwealth and Development Office (FCDO)[2] with two mutually reinforcing objectives: (i) to build the evidence case for how investments in resilient infrastructure and natural capital in EMDEs can strengthen UK systemic resilience to climate-related shocks; and (ii) strengthen knowledge on how the UK, through its foreign policies and development financing, can help close the resilience gap for infrastructure in EMDEs. Accordingly, the study focusses on three areas:

1. **New evidence of the materiality of systemic climate-related risks to the UK (hereafter 'transnational climate risks', TCRs) related to global supply chains, with a focus on infrastructure and natural capital**. The study reviews the literature and provides a series of new analytical case studies covering food, fuel, nature and trade networks.
2. **Review of the evidence on infrastructure financing gaps and opportunities for the UK to help close resilience gaps**, with a focus on understanding the barriers to investment and the role of development interventions, including blended finance.
3. **The role of data and new analytics in helping to mobilise finance**. We will review and develop suggestions for how new risk and impact analytics can inform more effective decisions and valuations by both public and private actors that can lead to increased mobilisation of private finance, with a focus on one sector.

The following chapter reviews the literature on TCRs and their relationship with infrastructure and the UK's systemic resilience. Chapter 3 presents case studies of the impact of grey and green infrastructure disruptions on UK trade and economy, focusing on food, ports, nature and green ammonia. The goal here is to illustrate the various dimensions of TCRs and what information is available to quantify and manage these risks. Chapter 4 then reviews current progress, challenges and future opportunities across six thematic areas: UK policy frameworks; adaptation and infrastructure finance; data; trade and supply chain resilience; regulation, and; global risk governance. Chapter 5 closes by suggesting next steps for addressing UK systemic resilience through a holistic approach.

2 The views and recommendations expressed in this report are those of the authors and do not represent those of the funders – the Oxford Martin School or the Foreign, Commonwealth and Development Office.

2. TRANSNATIONAL CLIMATE RISKS AND UK RESILIENCE – A LITERATURE REVIEW

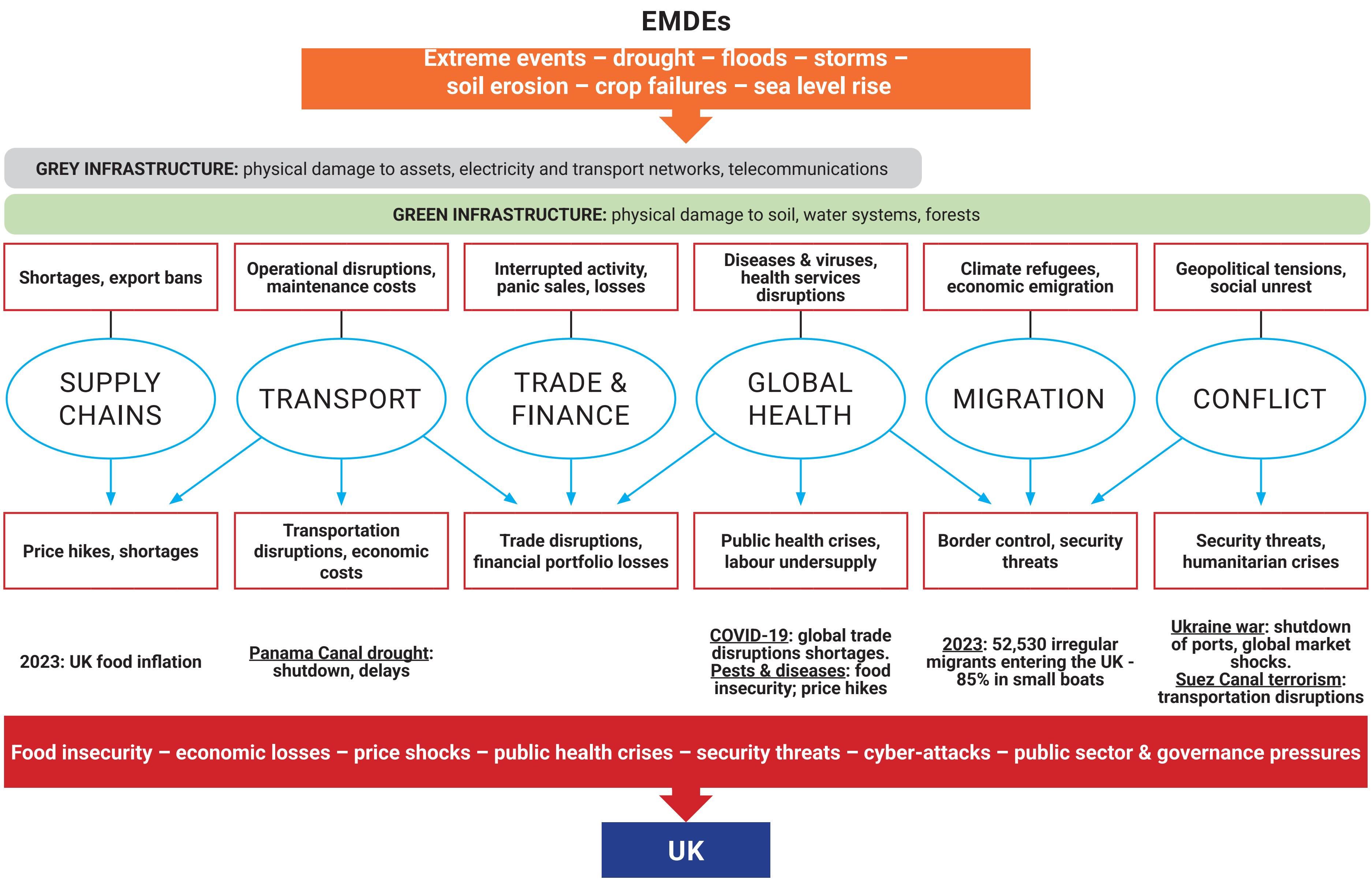
There is an emerging body of literature focused on conceptualising and exploring the mechanisms of 'cascading', 'borderless' and 'transnational' climate risks and impacts (e.g. Benzie and Persson 2019; Carter et al. 2021; Li et al. 2021; Pescaroli and Alexander 2018). The impacts of such risks are widely recognised to impact infrastructure, trade, security, migration and other areas of society at the country level. However, the systemic effects and implications for the UK remain largely under-examined (see e.g. Benzie and Persson 2019). This is despite the fact that the UK stands among the industrialised countries with a relatively high level of exposure to borderless climate risks according to emerging country-level approximations (e.g. Hedlund et al. 2018). The CCRA3 stresses that the 'urgency of action for some of the risks associated with the international dimensions of climate change is greater than previously assessed', notably in the areas of food security, violent conflict, public health and international law and governance (Climate Change Committee 2021).

This literature review draws together the existing knowledge regarding transnational climate risks to the UK from an economic and trade perspective. It combines diverse sources of information, including academic research, government studies and reports, and other relevant grey literature and official statistics. More specifically, the literature review will focus on the potential and reported risks to the UK in the context of (i) international supply chains (including food, fuel, energy and critical minerals); (ii) physical infrastructure (including ports, airports, roads); (iii) trade and finance, and (iv) natural capital.

The analysis will focus on meso-level risks affecting these different dimensions of UK trade, whilst acknowledging the broader implications, notably on security and migration (see Challinor, Adger, and Benton 2017; UK Secretary of State for Foreign, Commonwealth & Development Affairs 2023) and the indirect micro-level impacts on food poverty, rising inequality, social instability and other social issues in Britain.

The concept of TCRs will be utilised here as an umbrella term for climate-induced, borderless risks generated by different triggers (e.g. extreme events; floods, droughts; slow change); being transmitted through different kinds of mechanisms; representing different levels of complexity (e.g. cascading risks, spillover effects and compound risks, etc.); and, producing different types of risks for systemic resilience across diverse impact categories (e.g. trade, infrastructure, migration and conflict). In this report, we take an expanded view of TCRs to include transboundary environmental risks, which are closely interrelated with climate risks and, for many areas of risk, cannot (and should not) be meaningfully separated within risk management.

The framework below depicts the key TCR triggers in EMDEs with their impacts across the different impact categories to the UK. It does not capture impact or response transmission dynamics (Carter et al. 2021), but provides a high-level illustration of how TCRs can impact the UK.


EMDEs
Extreme events – drought – floods – storms – soil erosion – crop failures – sea level rise
GREY INFRASTRUCTURE: physical damage to assets, electricity and transport networks, telecommunications
GREEN INFRASTRUCTURE: physical damage to soil, water systems, forests
Shortages, export bans
Operational disruptions, maintenance costs
Interrupted activity, panic sales, losses
Diseases & viruses, health services disruptions
Climate refugees, economic emigration
Geopolitical tensions, social unrest
SUPPLY CHAINS
TRANSPORT
TRADE & FINANCE
GLOBAL HEALTH
MIGRATION
CONFLICT
Price hikes, shortages
Transportation disruptions, economic costs
Trade disruptions, financial portfolio losses
Public health crises, labour undersupply
Border control, security threats
Security threats, humanitarian crises
2023: UK food inflation
Panama Canal drought: shutdown, delays
COVID-19: global trade disruptions shortages.
Pests & diseases: food insecurity; price hikes
2023: 52,530 irregular migrants entering the UK - 85% in small boats
Ukraine war: shutdown of ports, global market shocks.
Suez Canal terrorism: transportation disruptions
Food insecurity – economic losses – price shocks – public health crises – security threats – cyber-attacks – public sector & governance pressures
UK

2.1 International Supply Chains

The world has witnessed a substantial internationalisation of trade and supply chains over the past decade. This has been spurred by favourable trade tariffs and lower investment barriers, multilateral trade agreements, technological advances and reduced transport costs (World Bank 2020). The UK prospers from an open economy and is dependent on global supply chains for energy, food, critical minerals and manufactured and traded goods. Estimations show that around 75% of UK manufacturing trade was 'dependent on simultaneous imports and exports' between 2018 and 2020 (see HM Government 2024, 6). As a result, supply chain disruptions that adversely affect imports of production inputs lead to lower domestic sales in the UK, as well as exports (Breinlich et al. 2023) – which can be further restricted by TCRs affecting global transport systems (see below).

As the UK's trade relationships expand and integrate imports from countries with limited social and environmental governance (ESG) and high exposure to climate risks, the UK's supply chains become increasingly fragile (Benton et al. 2019). Figure 1 illustrates some of the climate-induced business disruptions in companies under the British International Investment (BII) portfolio in Africa and Asia. Around 45% of African and nearly 40% of Asian companies in the sample have experienced adverse effects caused by flooding, drawing attention to the scale of climate-induced impacts on business in EMDEs.

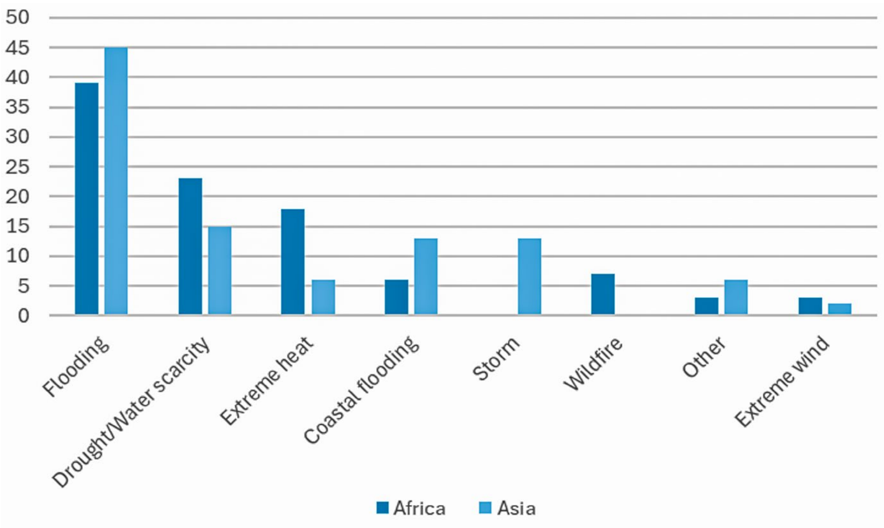


Figure 1. *Businesses affected by physical climate shocks in Asia and Africa in 2020 (percentage of companies and funds under the BII portfolio in Africa and Asia).*[3]

Source: Data from BII (2022).

Figure 2 illustrates the extent to which infrastructure disruptions reduce firms' utilisation rates (i.e. the percentage of employee's total working hours spent productively, or as 'billable hours') across low- and middle-income countries (LMIC). Rentschler et al. (2019) found that infrastructure disruptions generated $151 billion worth of utilisation losses in one year for 118 mostly low- and middle-income countries. The vast majority of global utilisation losses (over 2/3) are caused by unreliable transportation infrastructure, followed by electricity disruptions (causing a quarter of global utilisation losses) and minor effects attributable to water. Dents in utilisation rates reflect not only reduced profits, but also operational interruptions affecting supply chains and the economy more broadly.

3 Based on a survey of senior executives working across the BII portfolio of companies and funds in Africa and Asia.

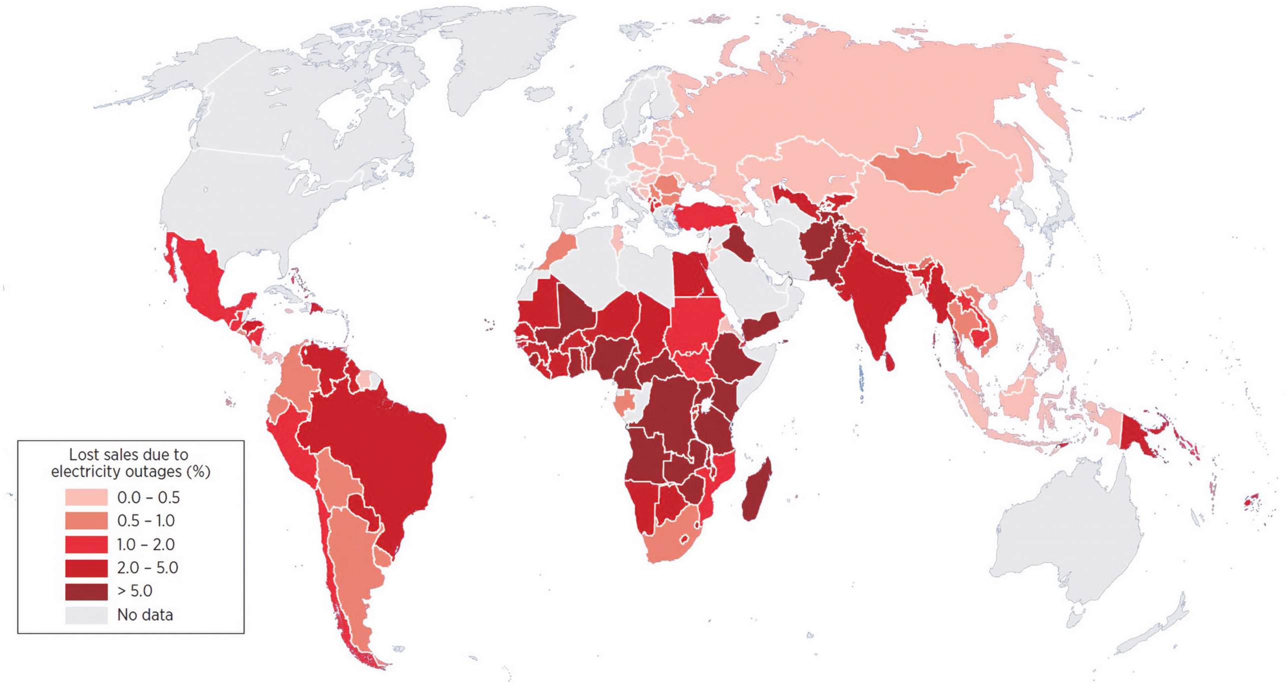


Figure 2. *Utilisation rate losses amongst LMIC firms due to electricity, water and transport infrastructure disruptions.*

Source: Rentschler et al. 2019; data from the World Bank's Enterprise Surveys and WEF.

For most products, supply chains are complex and thereby prone propagators for risks transnationally. Disruptions in supply chains can be caused by issues at (i) supply points (shortage of imported inputs); (ii) in the physical network, such as infrastructure and routes; (iii) damage to capital stock; (iv) in the demand for products, and (v) geopolitical situations (e.g. Climate Change Committee 2021). Disruptions in food production, for instance, often interact with related factors, such as biofuel policies that boost grain use for fuel or export bans, amplifying supply chain disruptions and creating food price spikes such as those in 2007–08 and 2010–11. TCRs resulting from supply chain disruptions vary depending on the type of products.

Food and agriculture products are perishable, which exacerbates risks around their availability. Fruit, vegetables, dairy, fish and meat, in particular, are highly perishable foods prone to climate hazards such as high temperature and humidity impacts during storage and transport (Bezner Kerr, Hasegawa, and Lasco 2022). At the same time, crop production is frequently disrupted by extreme weather events, which constituted half of all the shocks experience by the sector between 1961 and 2013 (Cottrell et al. 2019).

The UK has a much smaller agricultural sector than many other countries, such as the US, for instance. In 2021, the UK imported 42% of the total food consumed (HM Government 2023b, 101). Significant volumes of vegetables and fruit originate from water scarce countries, such as South Africa and Spain (Global Food Security n.d.), and other climate vulnerable countries. recovery, and reorientation—the three "Rs"The CCRA3 rates the UK risks regarding food availability, quality and price spikes as high, given the global climate threats to food production and supply chains (Challinor and Benton 2021). In a similar vein, a recent report by a major interdisciplinary research programme – *Resilience of the UK Food System in a Global Context* – highlights that 'there is an urgent need to enhance the resilience of food system outcomes to an increasing diversity, frequency and intensity of shocks and stresses' (GFS-FSR 2021).

The exposure of the British food sector to disruptions in global supply chains is illustrated by the 27% increase in food prices between 2021 and 2023.[4] Additionally, in January 2023, 17.7% of British households were food insecure, compared to 7.3% in July 2021 – representing a greater proportion than during the COVID-19 pandemic (see The Food Foundation in House of Commons 2023). The availability and affordability of food has significant social impacts, including food poverty and increasing public health challenges. The use of food banks, for instance, has increased exponentially over the past decade, with food parcels delivered by the Trussel Trust alone increasing from 0.3 million in 2012–13 to 3 million in 2022–23 (Pratt 2023).

Critical minerals are experiencing increasing global demand, given their use in technology and clean energy (the International Energy Agency estimates that demand will more than double between 2023 and 2030, with a continued, significant increase thereafter).[5] The effects of TCRs on critical minerals varies between mineral processing (monopolised by China) and mineral mining. Mineral processing or manufacturing in China is dependent on imports of mined minerals in Africa (Democratic Republic of Congo produces 70% of world's cobalt) and elsewhere, adding to the complexity of global critical mineral supply chains. Conflict, land grabbing and environmental pollution around mineral resources outweigh physical climate impacts in terms of causes of disruption to sourcing of minerals from Africa. For processed minerals, geopolitical tensions with China represent the primary transnational risk to supply chains, given the country's overwhelming dominance in the industry (IRENA 2023). This being said, TCRs are pertinent to thinking about and assessing risks to critical mineral supply chains, notably due to climate impacts on the (often poor quality) road infrastructure used by trucks transporting heavy minerals from the mines. At the same time, road infrastructure represents a significant ecological risk in mining regions (e.g. Damania et al. 2017), drawing attention to the need to carefully consider sustainable infrastructure investments in EMDEs.

The UK sources 12 out of 18 critical minerals from China, the remainder originating from distinct geographical locations including Brazil, DRC and Russia. As highlighted in the recent House of Commons committee report on critical mineral resilience, 'the UK is almost completely dependent on imports for critical minerals and mineral products' (House of Commons, and Foreign Affairs Committee 2023, 8). The report stresses the importance of access to critical minerals for the realisation of UK's climate action plans, stressing the role of geopolitical power dynamics with China hindering reliable supply – while omitting any climate-induced risks on the supply chains, or the broader systemic risks facing the global critical minerals supply system including key mining countries that systematically rank as highly vulnerable to diverse climate risks, water scarcity and vector-borne diseases. [6]

4 Office for National Statistics; see https://www.ons.gov.uk/economy/inflationandpriceindices/articles/costoflivinginsights/food#:~:-text=Food%20prices%20rise%2027%25%20in,'%20housing%20costs%20(CPIH)

5 See https://www.iea.org/reports/critical-minerals-market-review-2023/implications

6 See project 'Community climate resilience in critical mineral supply chains' by Stockholm Environment Institute: https://www.sei.org/projects/community-climate-resilience-in-critical-mineral-supply-chains/#:~:text=The%20communities%20and%20countries%20that,scarcity%20and%20vector%2Dborne%20diseases

Industrial products have supply chains that are also often complex and vulnerable to disruptions in transport systems (Ghadge, Wurtmann, and Seuring 2020; HM Government 2017). China remains UK's second largest trade partner for imports (after the US)[7], while the key trade routes in and out of the country (e.g. the Yangtze River and key ports) continue to be affected by drought, storms and other TCRs, causing significant disruptions in the production and supply of industrial products. Figure 3 shows UK imports of goods from markets with limited sources of supply, with the highest concentration in China due to its leading role in exports. This figure highlights the existing limitations on UK access to goods, which may be further jeopardised by climate-induced disruptions in different parts of the supply chains.

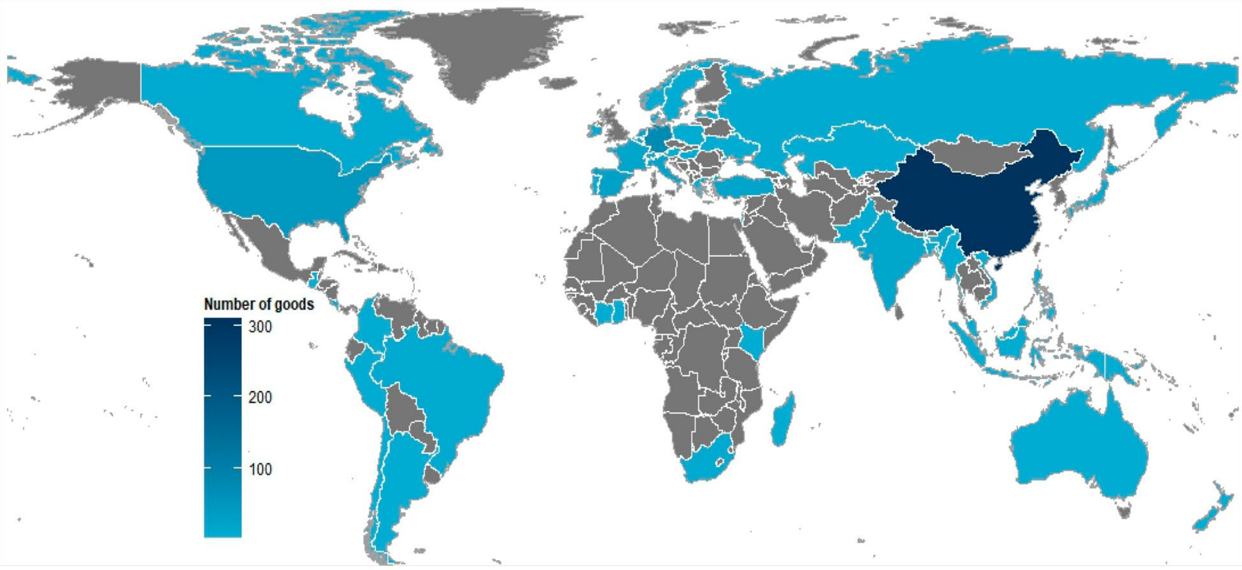


Figure 3. *Map of UK vulnerable goods imports (2021 trade data).*

Source: Critical Imports and Supply Chains Strategy 2024, 9.

Energy and energy security is a high priority for the British Government in the context of growing vulnerabilities to external shocks (HM Government 2023b). The UK has already reduced its use of Russian coal, oil and gas, and sources under one percent of its gas from Russia (data from March 2022). The Government has also increased its gas storage for emergency needs (HM Government 2023e). However, the country remains vulnerable to reduced availability and fluctuating prices of oil, under disruptions in oil trade routes. In the case of major physical disruption to oil markets, the UK can access emergency oil stocks through the International Energy Agency as a member of the collective and react to production and supply of fuels with the emergency powers granted under the Energy Act 1976. Climate related risks to fuel supplies can emerge through disruptions to trade routes (shipping). The landscape of risks may evolve in the future as patterns of dependencies change through the shift to renewables and green hydrogen.

7 See https://www.gov.uk/government/statistics/uk-overseas-trade-in-goods-statistics-january-2023/uk-overseas-trade-in-goods-statistics-january-2023-commentary, accessed 6.1.2024.

Box 1. Examples of climate- and environmentally-induced supply chain disruptions

- **2011 flooding in Thailand** caused disruption to major hard disk drive manufacturers increasing global prices of hard disk drives by 80–190% causing a total economic cost of $45.7 billion according to estimations by the World Bank (Climate Change Committee 2021).
- **2010 drought in Russia** combined with export bans and flooding in Pakistan reducing cereal yields, led to a global cereal shortfall, panic sales and increasing prices in the UK (Hildén et al. 2020).
- **Typhoon Doksuri in the summer of 2023** represented 'Beijing's worst flooding in more than 50 years, shuttering factories, ruining crops, collapsing homes and displacing tens of thousands of people. China's losses from natural disasters in July and August stood at an estimated $10 billion' (Daigle and Jessop 2023).
- **The COVID-19 pandemic** caused a 23% decrease in exports and a 12% cut in prices (per kg), creating a major pressure to businesses (Zurek et al. 2022)recovery, and reorientation—the three "Rs".
- **2023–24 drought impact on the Panama Canal,** putting at risk $270 billion worth of cargo annually. The canal manages 3–5% of global maritime trade volume and nearly 40% of all US container traffic traverses the canal. In early 2024, canal passings were reduced by 36%.

2.2 Transport and Infrastructure Systems

The World Bank reports that the infrastructure disruptions in low- and middle-income countries represent an annual financial cost between $391 billion and $648 billion (Hallegatte, Rentschler, and Rozenberg 2019), and UNOPS has estimated that infrastructure accounts for 88% of forecasted global adaptation expenses (Thacker et al. 2021). In line with these estimations, the SDG target 9.1 is to 'develop quality, reliable, sustainable and resilient infrastructure, including regional and transborder infrastructure.'

Global transportation and infrastructure system expansion and interconnectivity has been spurred by increasingly globalised and complex trade systems. While the transportation sector has come under scrutiny as a source of carbon emissions and a driver of climate change, the sustainability of transport systems is equally being affected by TCRs. This creates the double-challenge of creating both low-carbon and climate-resilient transport systems (Glock et al. 2021).

TCRs impact transport systems in multiple ways. For instance, seaports are critical for international supply chains and highly vulnerable to storms, flooding, as well as drought. Extreme heat, cold and floods affect road surfaces and rail lines and other areas of land transportation systems (e.g. De Abreu, Santos, and Monteiro 2022; Kostianaia et al. 2021). Markolf et al. (2019) have further highlighted indirect physical pathways for potential disruptions (such as power outages, water pipe breaks disrupting traffic), as well as non-physical risks (e.g. transport mode changes caused due to heat, high levels of accidents due to extreme precipitation; ICT outages disrupting traffic management or mapping services). Moreover, as highlighted by Wang et al. (2020), 'the climate change impacts could be further magnified because those posed at one location could pass to all sorts of aspects of transportation networks in other regions directly or indirectly especially in the cases of multimodal transport.'

The existing literature on climate risks in the transport sector remains limited (Wang et al. 2020). Nevertheless, the UK's third Climate Change Risk Assessment shows that climate risks to infrastructure represent 13 of the total of 61 risks and opportunities identified in the report (Climate Change Committee 2021).

Port and coastal infrastructure remains of particular relevance to the UK economy, given that around 95% of UK trade (by volume) is carried at sea. Moreover, the UK's export strategy *Made in the UK, Sold to the World* (2021) is promoting new and strengthened partnerships notably in the Indo-Pacific and other new markets located in climate vulnerable regions. The ferry services on the Dover-Calais and Dover-Dunkerque routes, as well as the Folkestone-Calais freight shuttle, represent the UK's key arteries for food imports, and any cascading effects of TCRs in this part of the UK transport structure could significantly harm UK food distribution (Zurek et al. 2022).

High levels of risks to ports globally are likely to create spill-over effects to the UK. Izaguirre et al. (2021) present a historical analysis of climate-induced risks on 2,013 ports around the world. The authors predict extreme risk levels by year 2100 for ports in the Caribbean Sea, Pacific Islands and Indian Ocean. Ports in the Arabian Peninsula (Persian Gulf and Red Sea) and the African Mediterranean are ranked in turn as very high-risk regions by 2100. The Indo-Pacific region, notably, is critical to the UK economy and security, while being home to 1.7 million UK citizens (HM Government 2021).

Similarly, Verschuur, Koks, Li, et al. (2023) explore multiple climate hazards and failure mechanisms across 1,340 ports globally, finding that over 86% of ports are vulnerable to more than three hazards (e.g. tropical cyclones, earthquakes, river flooding, pluvial flooding and coastal flooding). The authors find that, on average, $63.1 billion worth of trade is at risk annually, with high trade risk being concentrated in East Asian ports, which are prone to tropical cyclones and concomitant port downtime (over 5 days annually). Additionally, a previous report by Bailey and Wellesley (2017) emphasises the importance of global chokepoints for global trade, such as Red Sea routes (including the Suez Canal), the Straits of Hormuz and the port of Shanghai, which are often both geo-politically unstable and exposed to climate impacts.

Given the UK's dependency on trade with China, the above findings are also pertinent to the UK. In subsequent work, Verschuur, Koks, and Hall (2023) quantify the knock-on effects on trade partners, notably in terms of delays in ship arrivals at ports. Their findings show that ports with a lower number of trading partners are more vulnerable to the downtime risk caused by knock-on effects (e.g. the Middle East, Western Africa, South America). The authors estimate that around $81 billion worth of global trade is at risk annually in the current context of systemic risks to global maritime transport, trade and supply-chain networks.

Airports constitute one of the most sensitive parts of global transport systems. The UK's aviation sector is privately run, which translates to diverse operations, business models and approaches to planning and handling climate-induced risks (HM Government 2023b). At the same time, the UK air transport sector supports 1.6 million jobs and constitutes a key component of the export system.[8] The busiest air cargo routes for the UK include climate-vulnerable countries such as the United Arab Emirates, Qatar and India, as well as the US and Canada. Evidence in Yesudian and Dawson (2021) suggests that coastal airports, especially in Southeast and East Asia, are under particular threat of disruption due to rising sea levels. Given that these coastal airports also shoulder a disproportionately high volume of global passenger and freight traffic, such disruptions can also adversely affect UK trade and supply chains. However, studies examining systemic, borderless climate risks in the context of aviation remain few, and evidence from the EMDEs is conspicuously lacking (see Ryley, Baumeister, and Coulter 2020), making it difficult to assess potential implications and impacts for the UK aviation industry. Nevertheless, the UK was among the first countries to introduce legislation (2008 Climate Change Act) requiring major national infrastructure (including airports) to systematically report on identified areas of vulnerability to climate change.

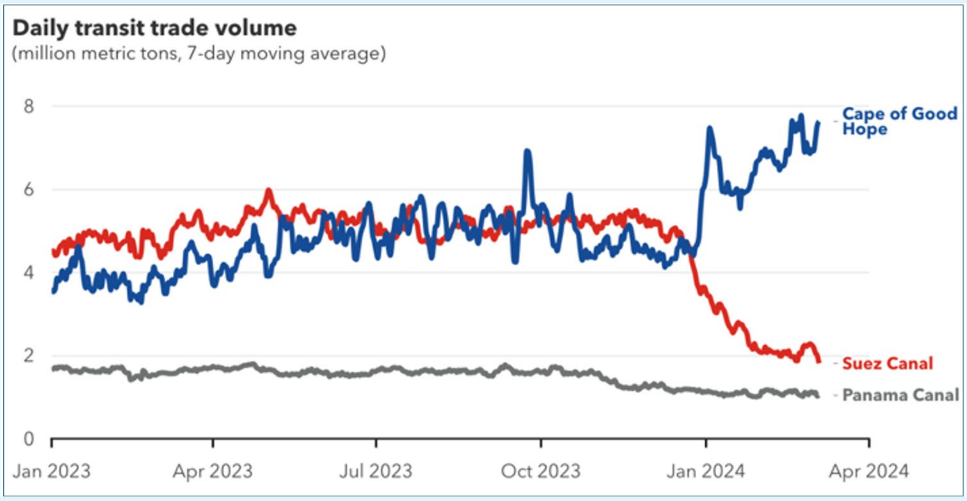
8 Data from 2018; see IATA https://www.iata.org/en/iata-repository/publications/economic-reports/united-kingdom--value-of-aviation/

Box 2. Examples: 2023-24 disruptions at Panama and Suez canals

The Suez and Panama canals are critical global shipping routes that have been affected by transnational risks in 2023–24, with significant impacts on maritime trade and shipping operations.

The Suez Canal is the shortest maritime route between Asia and Europe, and it normally covers around 13% of global maritime trade by volume. Following the Red Sea crisis and Houthi attacks on international commercial vessels since October 2023, multiple shipping companies are diverting ships to the Cape of Good Hope, South Africa. Between the two-month period from mid-December 2023 to mid-February 2024 alone, the number of commercial ships passing through the Suez Canal has reduced by 1,250 compared to the year before (representing around 1% of global maritime trade in 2023). While the transit volume through the Suez Canal is estimated to continue its decline, transit volume has increased by around 75% above last year's level around the Cape of Good Hope (as of February 2024). This longer trade route increases delivery times by 10 days on average, affecting especially companies with limited inventories. Monthly surveys by S&P Global show that the crisis has affected UK supply chains and the manufacturing industry, as raw materials, components and other goods are being re-routed alongside growing freight rates.

The Panama Canal is the most important maritime trade route between Asia and the US and the world's largest canal (representing nearly 5% of the global maritime trade). Since early 2023, the area has been hit by one of the worst droughts on record, which has significantly reduced water levels in the Gatun Lake. Water levels in this lake are key to regulating the locks on both side of the lake. As a result, the Panama Canal Authority had to impose various restrictions on the number of ships being able to cross. The transit volume has decreased by nearly 30% from November 2023 to the end of January 2024 compared to the previous year, increasing to 36% in early 2024.



Source: IMF Portwatch; UN Global Platform; S&P Global.

Road transportation is typically a key component in multimodal transportation and often constitutes the first part of the transportation journey in EMDEs. As such, climate resilience of road infrastructure in EMDEs is critical to well-functioning supply chains globally. Similarly to the aviation sector, evidence remains restricted.

Box 3. Examples of transport system disruptions

- Ports of Shanghai and Ningbo experience disrupted operations for 5 to 6 days each year due to extreme wind conditions.
- Following Hurricane Katrina (2005), the port of New Orleans was shut for almost 4 months.
- Trade disruptions at the port of Los Angeles-Long Beach, for instance, are estimated to cause a multiplier effect of 2.9 for each dollar traded through domestic supply chains (Wei, Chen, and Rose 2020).

2.3 Natural Capital

Natural capital can be defined, in simple terms, as the existing stocks of geology, soil, air, water and living organisms (Schumacher 1973). Natural capital is crucial for resilient economic systems, as over half of the global GDP relies on nature and nature services. At the same time, nature is arguably the single most important building block of any economy, given that 'there is no economy (or indeed, life) without these critical services, such as water, clean air and food' (Ranger, Alvarez, et al. 2023).

Green infrastructure, in turn, is closely connected to the management of natural capital. While being subject to diverse conceptualisations across geographical regions and disciplines (Matsler et al. 2021), most definitions of green infrastructure incorporate some aspect of planning into the natural and semi-natural infrastructure. For example, one definition describes it as a 'strategically planned network of natural and semi-natural areas with other environmental features designed and managed to deliver a wide range of ecosystem services' (Wang and Banzhaf 2018). In this report, we adopt a broad definition of green infrastructure, including planned natural and semi-natural areas for flood protection and erosion control, as well as the critical ecosystem services that underpin our life-critical systems and supply chains.

The importance of green infrastructure for trade and supply chains is increasingly recognised. According to the World Economic Forum, approximately $44 trillion of global economic value generation — over half of global GDP in 2019 — is moderately or highly dependent on natural assets and their ecosystem services provided by green infrastructure (WEF 2020). These natural assets and services – which can include fertile soils, clean water and air and pollination – are increasingly eroded globally by land-use change, pollution, overextraction and climate change, creating substantial risks to key supply chains globally.

As Marsden et al. (2024) underscore, losing critical green infrastructure and reaching ecosystem tipping points has dire impacts on the economy, from damaging assets (including infrastructure and real estate) to reduced energy and food security. At the same time, the resulting economic losses 'can transmit to financial institutions of all types through increased default rates, collateral value declines, market volatility, insured losses and inflation shocks' (Marsden et al. 2024, 4). The transnational nature of such risks is pertinent, as the impacts of going beyond ecological tipping points will be felt globally.

Climate impacts on natural capital, through environmental degradation and biodiversity loss, poses a significant risk to the UK economy and financial institutions. While existing research quantifying these risks remains limited, emerging empirical evidence presented by Ranger et al. (2023a) demonstrates that more than $5 trillion in value at risk globally is related to water alone, affecting notably the manufacturing and agriculture sectors. The authors also demonstrate that half of all nature-related risks, such as water scarcity, pollution and soil erosion, to the UK economy comes through international supply chains.

At the same time, the interplay between climate and nature risks is complex, and they can both mutually affect and exacerbate each other, leading to compound risks. Soil erosion, for instance, can lead to a more severe drought, which in turn intensifies negative impacts on food production (Ranger, Alvarez, et al. 2023). As such, nature risks can act as a multiplier on climate change. A key conclusion of Ranger et al. (2023) was that ignoring risks related to nature capital in climate risk assessments could lead to maladaptation.

2.4 Trade and Finance

London represents a key hub in the global financial network with one of the largest insurance markets in the world. The UK is also a major source of cross-border bank lending (covering 15% of such lending globally in the second quarter of 2022; HM Government 2023a); the City of London holds the largest share of global foreign exchange trading; and the UK is a leading actor in foreign direct investment, with the biggest portion of the FDI stock in Africa (FCDO 2023). The UK government has highlighted the direct and indirect exposure of the highly international UK finance sector to TCRs, while stating that 'the overall magnitude of the risk to the UK may be underestimated' (HM Government 2023b, 108).

The relationship between TCRs and trade is attracting attention, partially due to the increasing use of export bans and other trade restrictions to hedge against supply shortfalls (Townend, Aylett, and Benzie 2023). Indeed, climate impacts such as soil erosion, wildfires, droughts and flooding will cause financial losses and supply disruptions, potentially leading to export bans and new trade routes in the international trade system (Hildén et al. 2020), which in turn translates into price spikes and other disruptions at the domestic level in the UK. Research by Mandel et al. (2020) suggests that the UK is the second most exposed country to financial loss in coastal flooding scenarios even when counting for global adaptation.

Climate impacts can also directly affect UK **firms** via their operations and assets in climate vulnerable regions, including physical damage to assets, lower profits, impacts on costs of capital and insurance premiums, and reduced credit ratings (Hildén et al. 2020). A global survey of 100 major businesses shows that physical climate risks have already caused a 10% decline in annual sales and a 4% decrease in their market value (World Economic Forum and PwC 2023). Lower dividends, reduced equity and asset values can, in turn, impact **banks** through portfolio losses (Townend et al. 2023). The **insurance sector** equally faces investment losses and increasing claims payouts (Zhou, Endendijk, and Botzen 2023). The broader financial sector is affected by the changing perceptions of climate risks and the resulting expectations and behavioural changes, such as those related to insurance uptake or increasing risk premiums.

The area of TCRs has become an increasing focus for the financial sector, with growing evidence of the financial materiality to firms, including in relation to compounding risks (Ranger et al. 2022) and tipping points (Trust et al. 2023). For example, the 2023 guidance report of the Network for Greening the Financial System (NGFS) placed significant emphasis on the potential for cascading and compounding risks, and this was also addressed within two technical NGFS papers published the same year on compounding risks (NGFS 2023) and nature-related risks (Ranger, Alvarez et al. 2023).

Risk Category	Risk Example	Impact/Implication
Direct (Asset-Level) Physical Risks: extreme weather, floods, drought, wildfires, soil erosion either within the UK or to assets globally.	**Firm level**: damage to immobilised productive capital and assets; disruption to utilities and transport networks. **System level**: drops in property values.	**Firms**: production standby, productivity changes, lower profits, increased maintenance costs, asset value decreases, increased insurance costs, staff shortages. **Insurance companies**: claim payouts, investment losses. **Banks**: asset and collateral value depreciation, deposit withdrawals, nonperforming loans; negative impacts on bank credit supply and stability.
Indirect Physical Risks: transnational climate and nature-related risks to key supply chains, trade, confidence, the macroeconomic environment.	**Firm level**: supply chain disruptions, disruptions to inputs (power, water), price impacts. **System level**: less stable and conducive macroeconomic environment; trade export bans or rising import tariffs; price volatility.	**Firms**: productivity changes, lower profits, asset value decreases, increased insurance costs, rising costs of capital. **Insurance companies**: claim payouts, investment losses. **Banks**: asset and collateral value depreciation, deposit withdrawals, nonperforming loans; negative impacts on bank credit supply and stability.
Expectation/behavioural Risks	Increasing risk premiums in the bond and stock markets. Increasing demand for insurance and growing premiums. Lower stock returns, stock volatility.	**Bonds:** decreasing demand for bond credit; lower financing capacity of firms and governments; lower underwriting capacity of (re) insurers. **Insurance**: lower underwriting capacity, profitability, and stability. **Equity markets:** spillover effects to connected and aggregate stock markets.
Transition Risks	**Technological shocks**: drastic change in cost and performance of renewable energy production. **Policy/regulatory shocks**: new, sudden policies (e.g. global carbon tax; green supporting factor/ brown penalising factor).	Decreases in the value of fossil fuel-related assets and assets whose production input relies on fossil fuels or electricity. An unordered market response from market actors unable to incorporate policies in portfolio allocations; shocks to market share of carbon-intense firms; cascading risks.

Table 1. *TCRs for trade and the financial sector.*

Source: Authors' compilation based on Dolk et al. 2023, Monasterolo 2020, Zhou et al. 2023 and analyses presented in this report.

Moreover, it should be noted that the financial system remains exposed to growing transition risks related to climate change, referring to the 'economic and financial losses arising from the revaluation of carbon-intensive and low-carbon assets induced by a sudden change in policy and/or regulation that cannot be fully anticipated by financial actors' (Monasterolo 2020, 304). Trust et al. (2024) argue that the emergence of a major TCR could itself prompt rapid changes in policy that would generate even larger transition costs, resulting in an amplifying feedback loop between physical and transition risks. Ranger et al. (2023), in collaboration with NGFS, find that nature-related risks to the financial system are macro-critical. Based upon this evidence, Trust (2024) and Ranger et al. (2023) call for regulators and financial institutions to improve the representation of TCRs in current stress tests and scenario analyses required by financial institutions. Sam Woods, Deputy Governor for Prudential Regulation and CEO of the Prudential Regulatory Authority (PRA), has similarly called for more stress testing against extreme climate risks: 'The one thing that we are going to need to test is what would happen if we had a very large climate event in the UK, or possibly another major financial jurisdiction.'[9]

9 See https://www.theguardian.com/business/2023/sep/24/stricter-tests-city-copes-cli

3. UK SYSTEMIC RISKS: CASE STUDIES

This section provides four case studies to illustrate the vulnerabilities of the UK economy to TCRs and demonstrate how analytics can be used to understand and quantify the risks and inform policy, investment and decision making. The case studies cover aspects of food, natural capital, transport and energy, with a focus on green ammonia. This analysis builds upon research conducted as part of the Oxford Martin Systemic Resilience Initiative. The outputs in terms of risk quantification and hot spots of risks can inform the CCRA and UK FCDO planning and policymaking. We note that these case studies have not been selected because they represent the four most critical risk areas for the UK, but rather because they provide 'snapshots' of potential risks across different industries, sectors and risk domains.

3.1 CASE STUDY 1: TRANSPORT – Maritime chokepoints

With 80% of global trade volume being maritime, shipping is essential to the global economy. This is especially true for island nations such as the UK, where 95% of all import and export tonnage is carried by sea (Department for Transport 2021).

Global shipping in itself relies on a number of strategic trade routes and canals to facilitate maritime transport. Some of the most vulnerable points among global maritime trade routes are so-called maritime 'chokepoints' – often narrow, strategic passages with high volumes of maritime traffic. These chokepoints are prone to different types of risks, such as climate-related extremes, conflict, terrorist attacks, piracy, or blockages, as illustrated in Figure 4.

Recent events have highlighted how disruptions to chokepoints can cause large-scale maritime disruptions, which can affect supply-chains that rely on just-in-time inventory management. This includes the 2021 blockage of the Suez Canal, the drought in the Panama Canal that started in 2023 and has restricted the number of transits, and the Houthi rebel attacks in the Red Sea/Bab el-Mandeb Strait, which have forced ships to sail around the African continent.

Figure 4. *Overview of risks to a sample of global maritime chokepoints.*

Source: Authors' reproduction from Bailey and Wellesley (2017).

Here, we evaluate the UK's maritime and trade dependency on 12 maritime chokepoints located outside UK marine territory: Bab el-Mandeb Strait, Bosporus Strait, Cape of Good Hope, Gibraltar Strait, Korea Strait, Malacca Strait, Oresund Strait, Panama Canal, Strait of Hormuz, Suez Canal, Taiwan Strait, Tsugaru Strait.

We first evaluate the **UK maritime traffic dependencies** on various chokepoints. This captures the size of the vessels calling at UK ports that have travelled through a chokepoint prior to calling at the port ('incoming traffic') and the size of vessels leaving UK ports and next moving through a chokepoint before calling at another port ('outgoing traffic') (for methodology, see Appendix). UK dependencies on such chokepoints are illustrated in Figure 5. As expected, much of the incoming vessel traffic has travelled through Gibraltar Strait, serving ports in the Mediterranean and Northern Africa, before calling at UK ports. A smaller percentage of those trips through Gibraltar travel through the Suez Canal and the Bab el-Mandeb Strait. The other chokepoints contribute less to maritime traffic calling at UK ports. A similar pattern is observed for outgoing maritime traffic, although with smaller magnitudes. Outgoing traffic is more likely to call at other western and northern European ports instead of travelling back through the chokepoints.

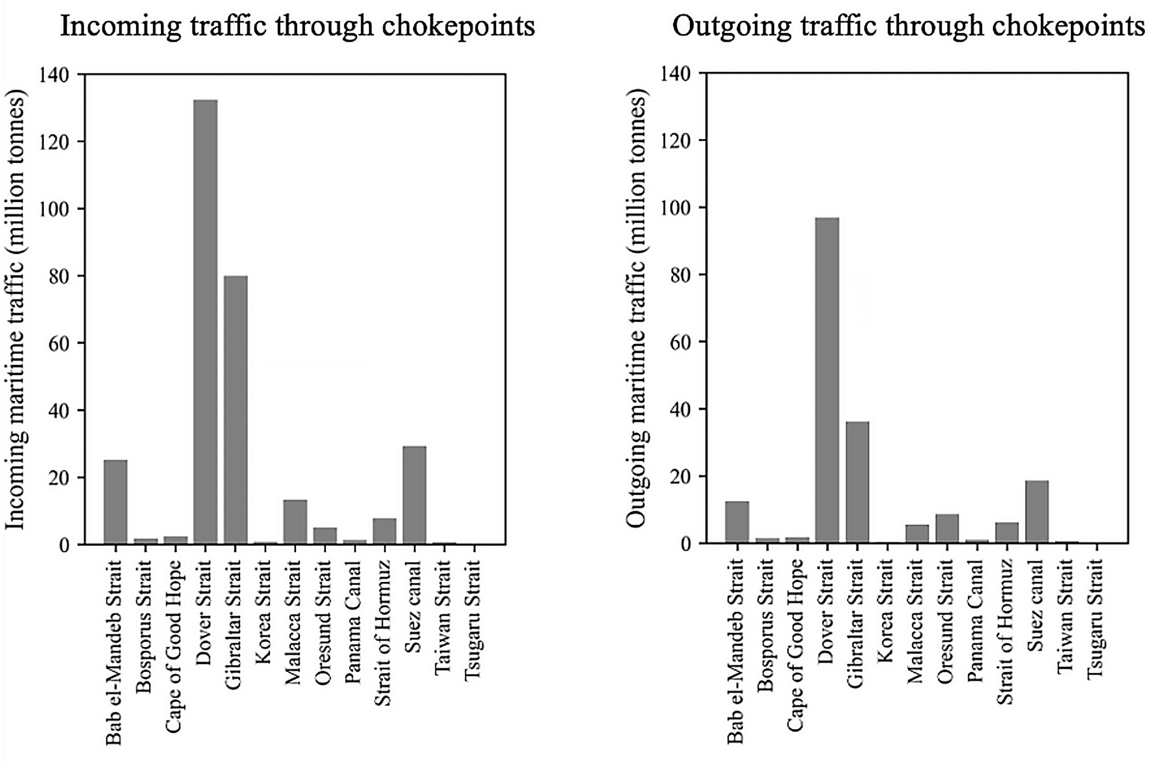


Figure 5. *UK maritime traffic dependencies on maritime chokepoints.*

Additionally, we can analyse UK maritime trade dependency on chokepoints (Figure 6). This captures whether UK imports or exports have passed any of the chokepoints en route, irrespective of whether vessels first called at other ports before calling at UK ports or after leaving UK ports. Around 40% of UK maritime import value comes through the Gibraltar Strait and around 25% of maritime imports pass through the Suez and Bab el-Mandeb. However, substantial shares of trade travel through chokepoints on the other side of the world, including 20% of maritime import value passing through the Malacca Strait. The export dependencies are smaller, both in absolute terms and share. Still, 15–20% of maritime exports are moving through the aforementioned chokepoints.

The analysis presented highlights the UK's foreign dependencies on global maritime chokepoints and the potential economic repercussions should some of these chokepoints be disrupted for a prolonged period. Our findings also show that the risk of disruptions is higher for chokepoints such as the Suez Canal, Bab el-Mandeb and the Taiwan Straits, which together handle a substantial share of maritime imports and exports. As such, ensuring security in these regions offers a clear economic benefit for the UK in the long term.

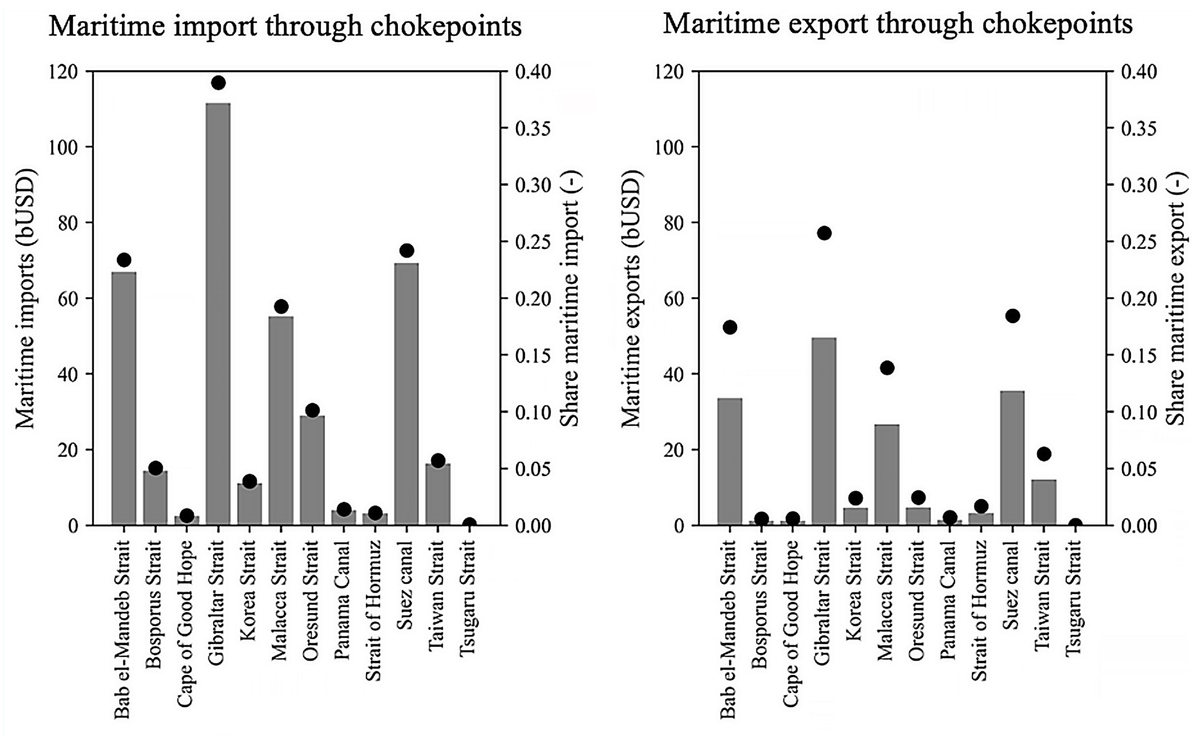


Figure 6. *UK maritime trade dependencies on maritime chokepoints (trade is expressed in value terms in 2021 USD; the bar corresponds to the left axis, while the marker indicates to the right axis).*

Climate risks to ports

Beyond the maritime chokepoints, the UK relies on ports all over the world to facilitate UK imports (UK imports that are being exported or transhipped at foreign ports) and exports (UK exports that are being imported or transhipped at foreign ports). Compared to chokepoints, where the UK maritime trade is concentrated, a more diverse set of ports globally are handling UK trade.

Localised shocks to these foreign ports can negatively impact port operations and subsequently affect maritime traffic to and from UK ports, or entire trade flows that originate from, or are destined to, the UK. Here, we evaluate the top climate vulnerable ports for the UK outside of the country. Climate vulnerability is defined as the combination of the amount of UK trade that is at-risk of being disrupted by climate-related disruptions happening at ports. By means of example, if a port in a foreign country handles $10 million of UK trade flows and climate-related hazards can shut this port down on average 5 days per year, the climate vulnerability of this port is (5/365) * 10 = $0.13 million per year.

In previous research, both the foreign maritime trade dependencies and the climate-related risk to specific ports have been quantified. For the purposes of this analysis, we define climate risk as the expected annual downtime of ports associated with cyclone wind, coastal flooding, river flooding, pluvial flooding, and weather extremes that shut down ports (e.g. waves, extreme temperatures). This is capturing the present-day climate risks to these ports of the entire spectrum of likely events that can occur, including low-probability but high-impact events.

Similarly to the chokepoint analysis, the climate vulnerability of ports can be evaluated in terms of maritime traffic (direct shipping connections from and to UK ports) and maritime trade flows (maritime trade dependencies on UK ports, irrespective if there are direct shipping connections).

Figure 7 shows the top 30 most climate vulnerable ports for the UK in terms of maritime traffic, expressed in maritime traffic capacity at-risk of being disrupted. Some of the most climate vulnerable ports are located close to the UK, including the ports of Le Havre, Rotterdam, Zeebrugge, Antwerp and Mongstad, given large UK maritime dependencies on these ports and some coastal flooding threatening these ports. This top 30 also includes a number of ports with high trade dependencies in the USA, which are particularly prone to hurricanes. Outside of the EU and North America, only the port of Yantian in China and Port Elizabeth in South Africa show as climate vulnerable, given moderate traffic dependencies but high climate risk.

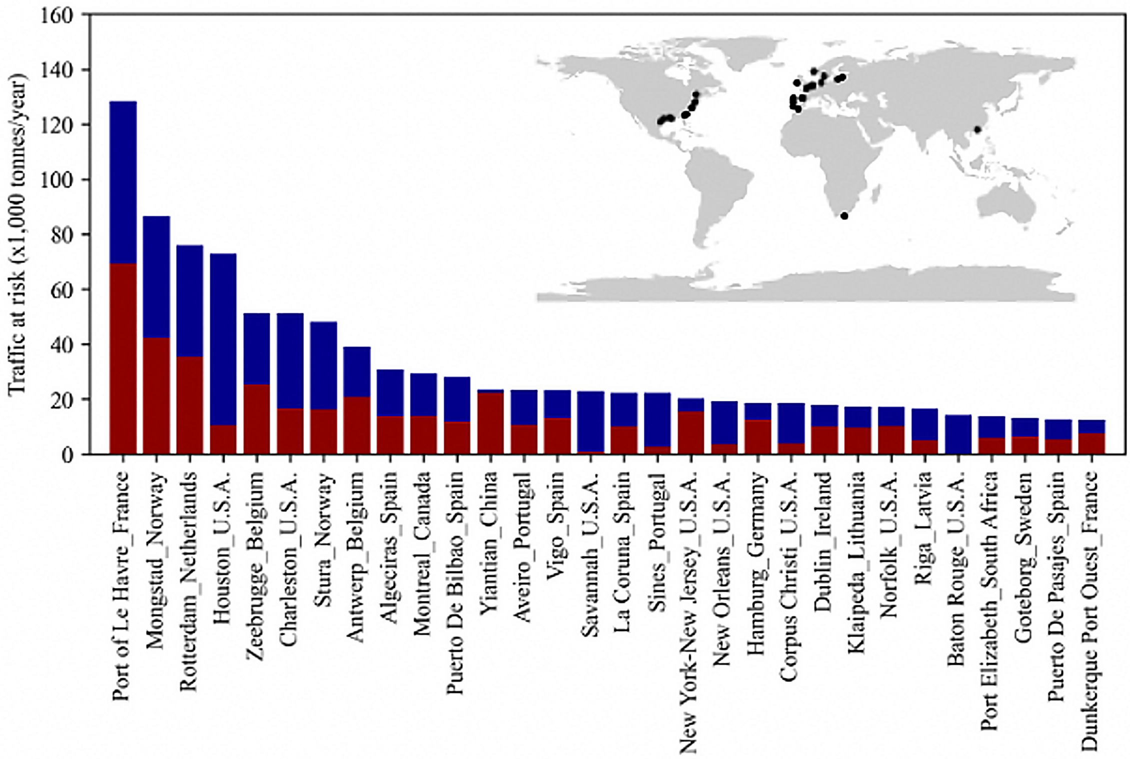


Figure 7. *Top 30 most climate vulnerable ports for the UK in terms of total traffic. The blue colour indicates incoming traffic and the red colour outgoing traffic.*

The most climate-critical ports in terms of maritime trade value at-risk for the UK are more dispersed around the globe (Figure 8). The most climate vulnerable ports are now in the United States, including the ports of Charleston, Savannah, Houston and New York-New Jersey. However, ports in Asia, including the ports of Pusan (South Korea), Yantian (China), Kaohsiung (Taiwan), Shekou/Shenzhen (China) and Shanghai (China) are now becoming more critical for the UK, given that they handle large maritime import values (manufactured goods) and are prone to typhoon impacts.

The climate vulnerability of the top 30 ports ranges from around $20 million per year to $150 million per year. In total, all trade risk for the UK due to climate-related port disruptions is $2.5 billion per year. However, this metric should be interpreted with care, as disruptions to ports do not necessarily cause trade to be lost. Instead, it merely delays trade, and only in extreme cases lead to reduction of trade at the end of the financial year. However, it is an adequate metric to compare and contrast ports and get a sense of the amount of maritime trade value that is at-risk every year of facing climate-related disruptions.

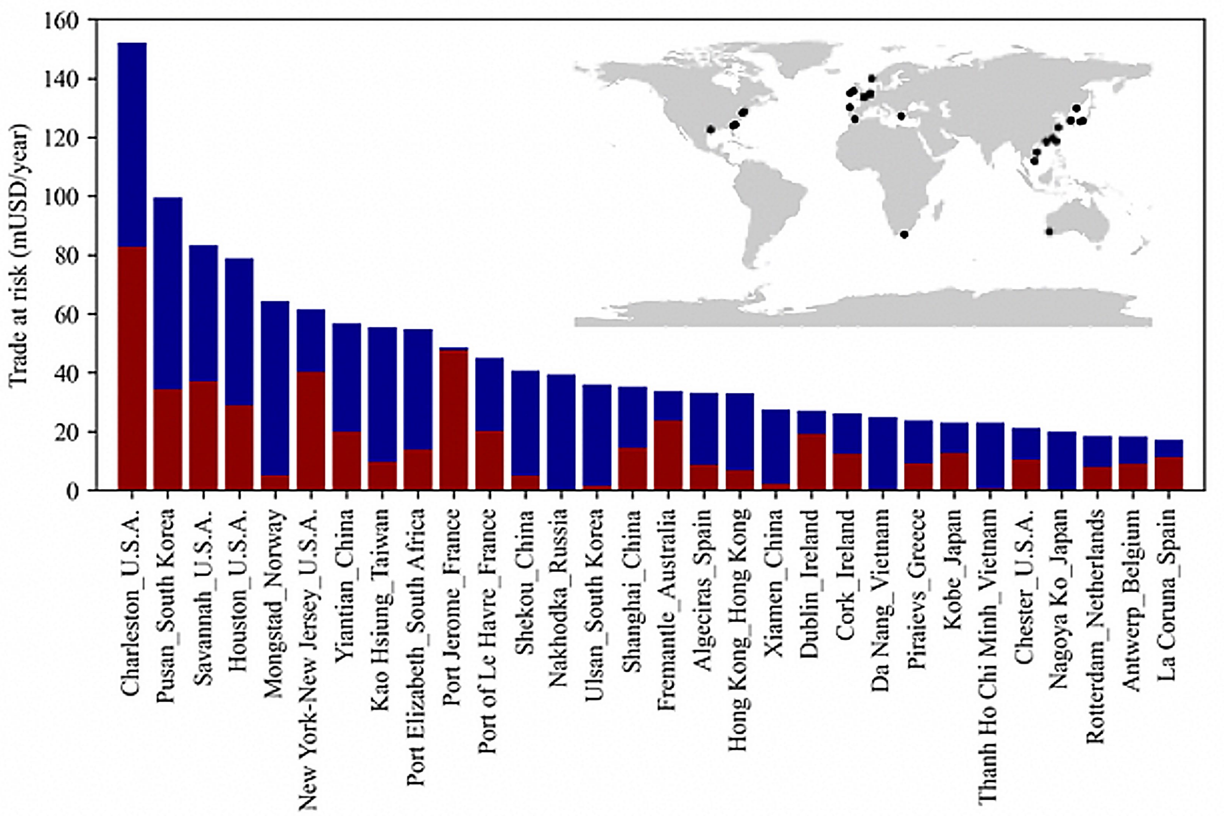


Figure 8. *Top 30 most climate vulnerable ports for the UK in terms of total maritime trade. The blue colour indicates UK imports and the red colour represents UK exports.*

Based on this case study, we can draw the following conclusions:

- A major share of UK trade flows through maritime chokepoints that face maritime security risks. Compared to non-climatic risks, climatic risks are likely to be minor. In terms of non-climatic risks, the hotspots for the UK are the Bab el-Mandeb Strait (due to regional conflict) and the Suez Canal (due to terrorist attacks). Given the high rerouting costs and the volume of trade passing through these chokepoints, disruptions can impact UK suppliers and, in extreme cases, drive inflation.
- In total, the climate-related risks to UK trade caused by port disruptions is around $2.5 billion per year. The key ports driving these risks are located in the USA, South Korea, and East and South-East Asia. In the future, with shifting trade patterns and elevated climate risks, these key hotspots may change.
- This analysis underlines that facilitating adaptation finance to foreign ports is key to safeguard future trade flows from and to the UK.

3.2 CASE STUDY 2: FOOD - Shocks to global grain supplies affecting the UK

The UK imports around 50% of the food it consumes and is consequently exposed to disruptions to food supply chains internationally. Moreover, the UK imports a variety of agricultural products for food and beverage supply chains, as well as animal feed. Dependencies vary significantly across different foods based on the UK's own production. For instance, the UK produces only 16% of fruit consumed domestically, and just over a half of the vegetables (Department for Environment, Food and Rural Affairs 2023). Nearly half of UK banana imports are sourced from countries experiencing high risks of climate catastrophes; nearly a quarter of the UK's annual coffee import land footprint comes from countries that experience high or very high climate vulnerability; and nearly a quarter of UK cocoa imports originate from six producer countries experiencing high or very high risks for loss wetland habitat, grassland and forest as a result of land-use changes (Fairtrade Foundation 2023).

This case study examines the impact of shocks on cereals and rice given that these constitute just over a quarter of energy for adults in Europe[10] and more so as a feed for animals.[11] Currently, the UK imports only around 2–2.5 million tonnes of wheat annually, while it produces around 15 million tonnes domestically. Global exposures are higher for other grains. Around 2.5 million tonnes of maize is imported, with limited domestic production, as well as around 1 million tonnes of soybeans (not including soybean meals). The poultry industry, in particular, is dependent on soy imports that are highly concentrated on few producer countries (over 75% of soy being sourced from Argentina, Brazil and the US; West 2021). Rice is less widely imported, with annual imports at around 175,000 tonnes, which are all consumed.

The global grain supply faces risks from many different types of shocks, including weather-driven variability in yields, energy price spikes, conflict (e.g. the Ukraine war), and countries imposing export restrictions. These shocks abroad can impact prices in the UK, as producer prices rise in exporting countries, or because the UK has to change its distribution of suppliers.

Impacts of various shocks on UK grain imports

Based on a new global grain trade and price model developed at the University of Oxford (Verschuur et al. *forthcoming*), we can simulate the impacts of various shocks on UK grain imports. A series of scenarios are run with the model, which we can use to quantify deviations of consumer prices of grain commodities in the UK. The analysis focuses on maize, wheat, rice and soybean. The following compound risk scenarios are included:

- **Base**: 54 years of realistic weather variations[12] across breadbaskets globally that cause yield fluctuations.
- **Ukraine supply shock**: 54 years of weather-driven yield variations on top of a supply shock to Ukraine production and inability to export grain outside of Europe.
- **Energy price shock**: 54 years of weather-driven yield variations on top of an energy price shock that increases the production prices of grains in producer countries following increases in fertiliser, pesticide and diesel prices.
- **Trade restrictions**: 54 years of weather-driven yield variations on top of export restrictions implemented by countries to restrict imports or exports of certain crops. We include a total of 126 restrictions for maize, 139 restrictions for rice, 229 restrictions for wheat and 52 restrictions for soybean.
- **Compound**: 54 years of weather-driven yield variations on top of all the shocks combined.[13]

The bar charts in Figure 9 illustrate the median consumer price increase for the UK across the 54 weather simulations, the markers being the individual simulations. As shown, in the base scenario, the weather-driven variations cause only moderate fluctuations in the UK consumer prices (around 10% up or down).

10 Data source: Food and Agriculture Organization of the United Nations via Our World in Data.

11 As above, for the UK, risks to fruits and vegetables are higher currently.

12 Based on 54 years of historical weather variations, which are impacting present-day yield and production regions. This draws on re-analysis data (see Tuninetti and Davis 2024).

13 The deployed model here is a 'one-off shock' model and not a time series, where conditions in one year are the input for conditions in the next year. To do other type of complex/compound hazards (like a sequence of disasters), the time and/or spatial resolution of the model needs to be adapted.

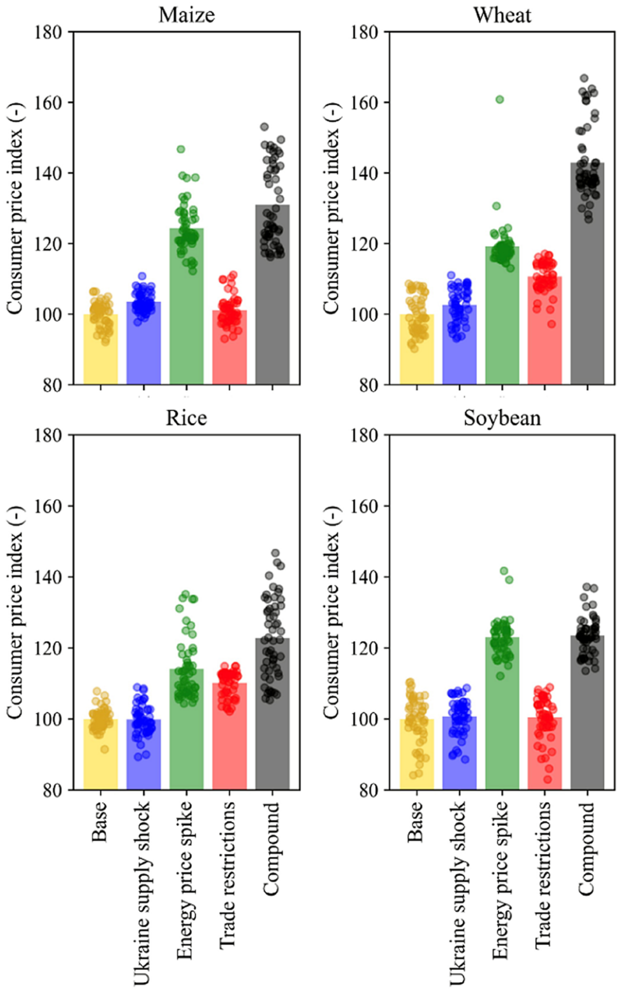


Figure 9. *Median (50th percentile) consumer price index across the 54 weather-year simulations (bar chart) combined with the 54 weather-year simulations per scenario on consumer price index (marker).*[14]

The *Ukraine war scenario* has limited impact on the UK, despite high maize imports from Ukraine. The consumer prices increase only slightly, but within the model, the UK is able to source more maize from alterative suppliers to meet the supply gap. The implementation of *trade restrictions* has limited effect on the consumer prices of soybean and maize, and some increase in wheat prices and rice prices.

The *energy price shock*, in turn, increases the consumer price index by around 15–20 percent in the median year, with the largest sensitivity observed for soybean and maize. Altogether, the consumer price index can increase by 20% to 40%, depending on the crop. However, the *combination of all shocks*, along with an extreme case of a poor yield year, can cause consumer price fluctuations of 50% to 60% above the baseline level. This highlights that the UK's cereal prices are influenced by shocks abroad.

14 Index 100 refers to the mean consumer price under the baseline run across the 54 weather-years.

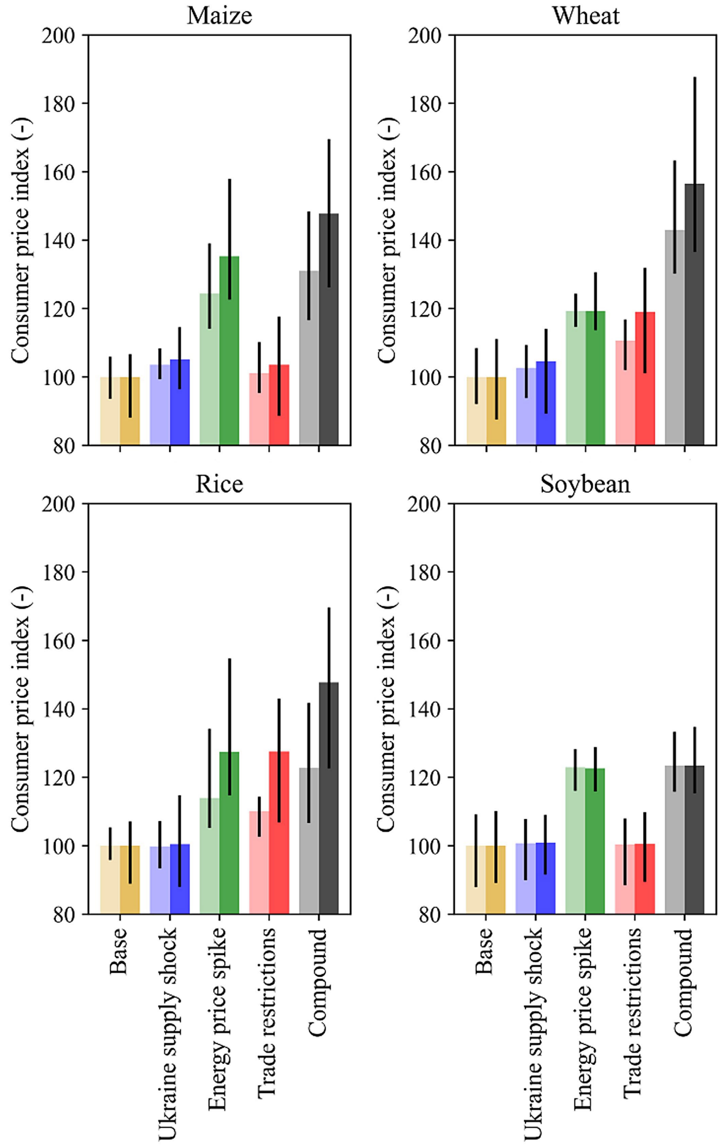


Figure 10. *Median (50th percentile) consumer price index across the 54 weather-year simulations (bar chart) for the UK (light shading) and the global (dark shading). The error bars indicate the 5th to 95th percentile.*[15]

Moreover, we compare UK consumer price fluctuations to global consumer price fluctuations in the model (i.e. the globally weighted consumer price, weighted by final demand) (Figure 10). Lower consumer price fluctuations indicate that the UK grain supply system is, overall, better able to cope with different shocks compared to the global system, particularly for rice, wheat and maize. For soybean, the difference is negligible, mainly because the UK relies on the main global soybean suppliers. As such, the UK's reliance on different suppliers (i.e. existing supply diversification) and domestic wheat reliance are effective ways to buffer climatic and non-climatic shocks. However, this can be improved in the future.

15 Index 100 refers to the mean consumer price under the baseline run across the 54 weather-years.

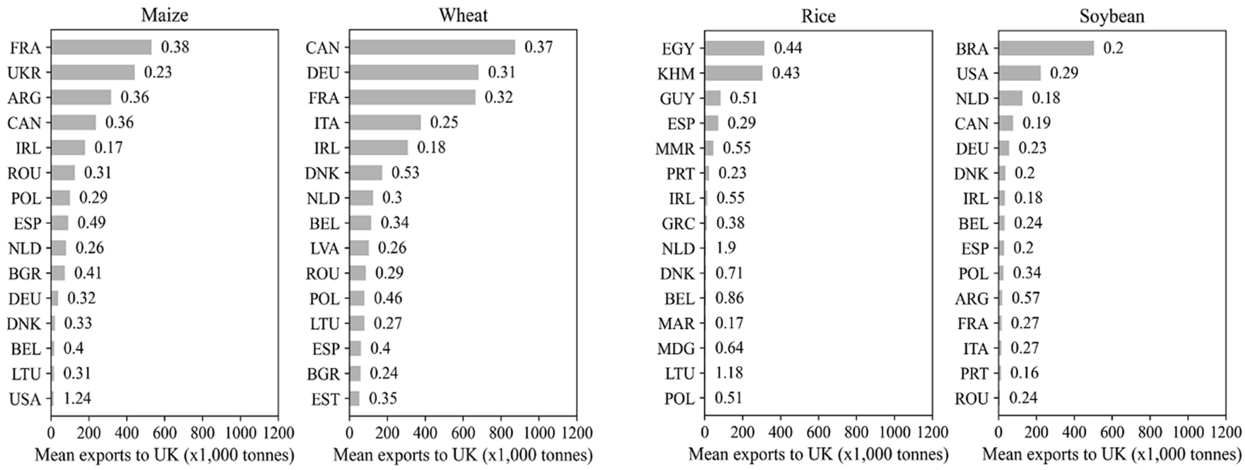


Figure 11. *Top 15 largest supplier countries across the 54 weather-year simulations run for the four crops assessed (size of bar), with the coefficient of variation in supply to the UK across the 54 weather years (data label).*[16]

Finally, we examine the supply reliability of the UK's food-exporting countries, measured by the coefficient of variation across 54 weather years (Figure 11). For maize, Ukraine represents a more stable provider compared to France, Argentina and Canada. For wheat, all top-producing countries experience year-to-year supply fluctuations to the UK, while stable imports come from Italy and Ireland. The top importers of rice are among the most variable, with year-to-year differences in the sources of the UK's rice. Supply trends for soybean, in turn, are stable, with less year-to-year variations. Such analyses can be used to build national strategies for food supply resilience by analysing different options for diversification under various shock scenarios.

Impacts of a breadbasket failure scenario for the UK

Globally, the vast majority of grain supply originates from a handful of regions; these are often known as the *breadbasket* regions. Climate and crop modelling studies have shown that the chance of these breadbaskets being disrupted by climate events (e.g. droughts) will increase with climate change, with significant impacts on global supplies of grains. Other environmental pressures, such as soil erosion and salinisation due to over-intensive use of land could further amplify these risks. The potential impact of such disruptions on UK supplies and prices has not yet been explored. In this report, we present a preliminary assessment of this potential impact.

A global breadbasket failure scenario could impact the UK in two different ways: by affecting the global top grains producers (a *global* breadbasket failure) or by affecting top grain producers for the UK (referred to here as a *regional* breadbasket failure). We assess and compare both scenarios. In this study, a breadbasket failure is defined as the worst-case yield variability (as described above) for each producing country, without assigning a probability to these events occurring across multiple producing countries. The landed costs include the cost of producing the grains and supplying them to warehouses in the UK, excluding subsidies or marketing margins.

16 For example, for soybean, Brazil is the largest supplier to the UK and has a relatively stable supply (relatively low coefficient of variation of 0.2).

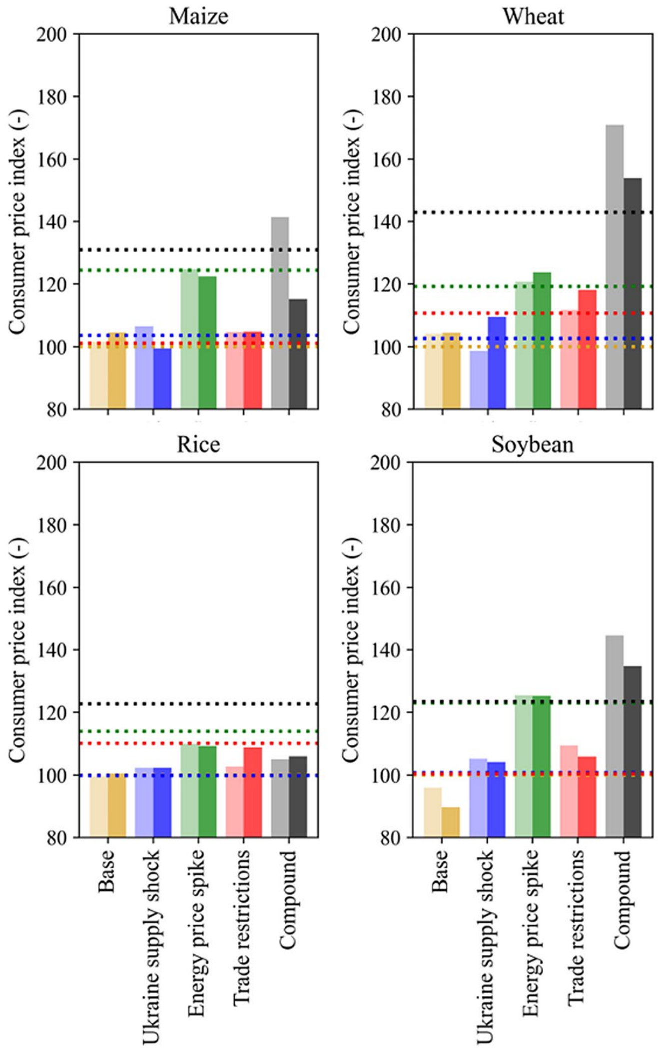


Figure 12. *Consumer price index for the two breadbasket failure simulations*[17] *(darker colour indicates global breadbasket failure; lighter colour indicates regional breadbasket failure; dashed lines indicate the mean consumer price under different scenarios as outlined above).*

Figure 12 shows whether a global (darker colour) or regional (lighter colour) breadbasket failure has a greater impact on UK grain prices under the baseline scenario (in yellow) and additional non-climatic shocks. Under the baseline, a global breadbasket failure increases prices more than a regional one, except for soybeans. However, in the compound shock scenario – particularly for maize and wheat – a regional breadbasket failure drives prices up significantly more. In other words, under normal conditions, the global supply system has some flexibility to buffer against regional breadbasket failures. However, when additional stress impacts the system, a regional breadbasket failure can significantly increase prices due to limited alternative suppliers. This underscores the importance of carefully monitoring the regional supply network – particularly for wheat and maize – to better understand potential consumer price shocks.

Furthermore, the analysis shows that the impact of both global and regional breadbasket failures is comparable to the impact caused by the Russian invasion of Ukraine. In the compound risk scenario, a regional breadbasket failure increases maize prices by an additional 10% beyond the compound

17 Index 100 refers to the mean consumer price under the baseline run across the 54 weather-years.

risk alone, soybean prices by 15% and wheat prices by around 20%. For rice, the effects of regional or global breadbasket failures on the UK are less severe than the normal weather variability inherent to rice supplies. Some preliminary conclusions from this analysis are the following:

- Weather variability alone can cause fluctuations in UK grain prices, but typically within the range of 10–15%. However, when additional stress is imposed on the food system due to non-climatic shocks, weather variability can lead to significantly greater year-to-year fluctuations. This underscores the vulnerability of the UK supply system to compound shocks. Consequently, monitoring and early warning systems should be implemented to assess the potential for compounding impacts – these systems and assessments should be integrated into the UK's food system resilience strategies.
- The UK grain supply system has existing levels of resilience, particularly through supply diversification and strategic supply dependencies that are less prone to global failures. Our analysis indicates that the UK grain supply is currently more resilient than the global grain supply, as reflected in price fluctuations.
- However, the UK grain supply network is more vulnerable to breadbasket failures among its main suppliers than the largest global grain suppliers. This suggests that regional monitoring is more important than monitoring global markets.
- From a foreign policy perspective, improving sourcing quantity and reliability from countries with negatively correlated yield variability may be considered a policy priority. However, supplier choices are influenced by many factors, including seasonality, non-cost barriers, reliability, transaction risk, and deforestation impacts, among others. Hence, a balanced approach is needed when considering trade-offs between lower import prices and other policy objectives.

3.3 CASE STUDY 3: NATURE – International supply chain risks related to the erosion of natural capital globally

Recent research by the University of Oxford with the Green Finance Institute and wider partners assessed the materiality of nature-related risks to the UK economy (Avery, Ranger, and Oliver 2024). The study clearly demonstrated that the erosion of UK and global natural capital generates significant and long-term risks to society and the UK economy, including increasing risks of pandemics, floods and droughts; undermining water supplies; damaging agricultural production; and creating risks to human health. These risks can have major and persistent implications for entire sectors, economies and the financial sector. An important finding of this research – directly relevant to this study – is that **at least half of the nature-related economic and financial risks to the UK economy originate from overseas via international supply chains**. This includes risks of disruptions to many supply chains of raw and manufactured goods internationally due to a wide range of factors, including soil erosion, water scarcity, pollution, loss of pollinators, ocean acidification and rising climate risks associated with deforestation and land-use change.

Figure 13 illustrates the main four channels through which risks related to the degradation of natural capital can impact the UK economy and financial institutions, including government fiscal balances. These include the direct impact of supply chain disruptions on UK firms and the impact of changing global macroeconomic conditions on the wider UK economy, for example, through changing in prices, trade balances, investment premia and currency. The erosion of natural capital can also directly affect the financial system and firms through the direct ownership of entities overseas and other financing activities, such as insurance, lending and investment. The scale of the UK's interconnectedness with the global economy means that it is particularly exposed to these international risks. **The study estimated that the £3.8 trillion in assets from UK banks and insurers assessed are dependent on a wider set of assets through supply chains, which may represent approximately £5.8 trillion of assets**. Of this total, £3.2 trillion – or 56% of total upstream exposure – is highly or very highly dependent on nature.

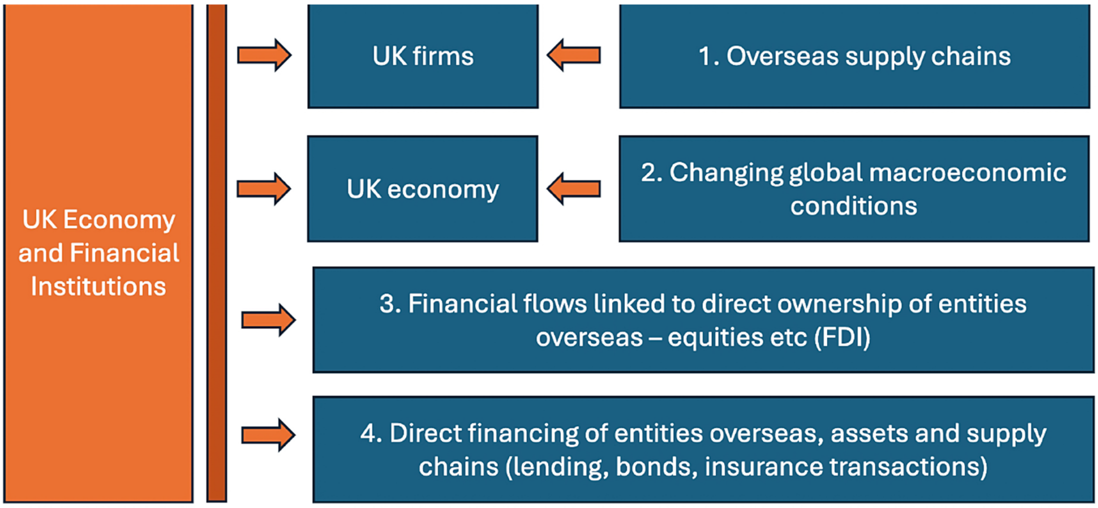


Figure 13. *Transmission channels through which the international degradation of natural capital can impact the UK economy and financial system.*

Focusing on risks related to supply chains, Figure 14 illustrates how the calculated nature-related value at risk for the seven largest UK banks is driven by exposures across different countries for four example ecosystem services: ventilation (air pollution), pollination, surface water (water scarcity) and soil quality. The green portion of each bar represents the risk derived from UK domestic ecosystem services. Some banks are significantly more exposed to international risks than others. Beyond the UK, the largest sources of risks to UK financial institutions come from the United States and Latin America, Asia and the Middle East.

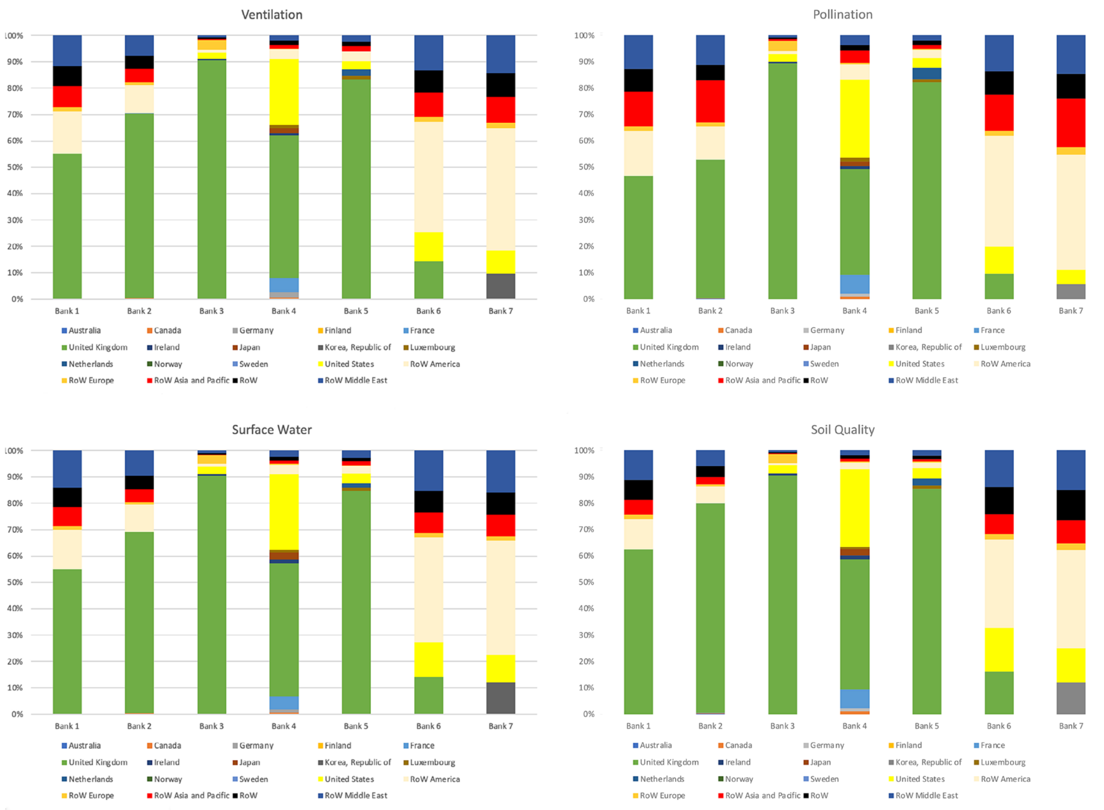


Figure 14. *Nature-related value at risk for the seven largest UK banks, shown by type of ecosystem service and country (Avery, Ranger, and Oliver 2024)*

The study also assesses the potential impacts on the UK economy and financial system of the wider macroeconomic impacts of natural capital degradation overseas. It does so through two scenarios, which aim to capture different dimensions of the risk. The first scenario is an international supply chain scenario and the second is a health-related scenario, driven by the increased risk of pandemics linked to environmental degradation. Given its relevance to this study, we focus on the international supply chain scenario, illustrated in Figure 15.

The scenario includes two components: first, a chronic component, which includes continued stresses to ecological systems across many countries, affecting key ecosystem services (water, pollinators, pollution, soil quality); and second, an acute component, taking the form of a strong El Niño, leading to reduced precipitation across many food and natural commodity-producing regions. These impacts are compounded by ongoing soil erosion, deforestation and overextraction of water. These combined effects lead to significant loss of crop production in some of the world's largest agricultural regions – creating a 'multi-breadbasket failure' as well as disruptions to other key commodity supply chains (biofuels, fruits) – and triggering knock-on effects for global commodity prices and the financial system. This scenario is multi-dimensional, capturing the complexities of multiple drivers acting at different scales at the same time with global macroeconomic impacts. Figure 16 demonstrates the impacts of the scenario on UK GDP, simulated using the NiGEM model (Avery, Ranger, and Oliver 2024) (in blue) and compares it with the effects of the two other scenarios studied.

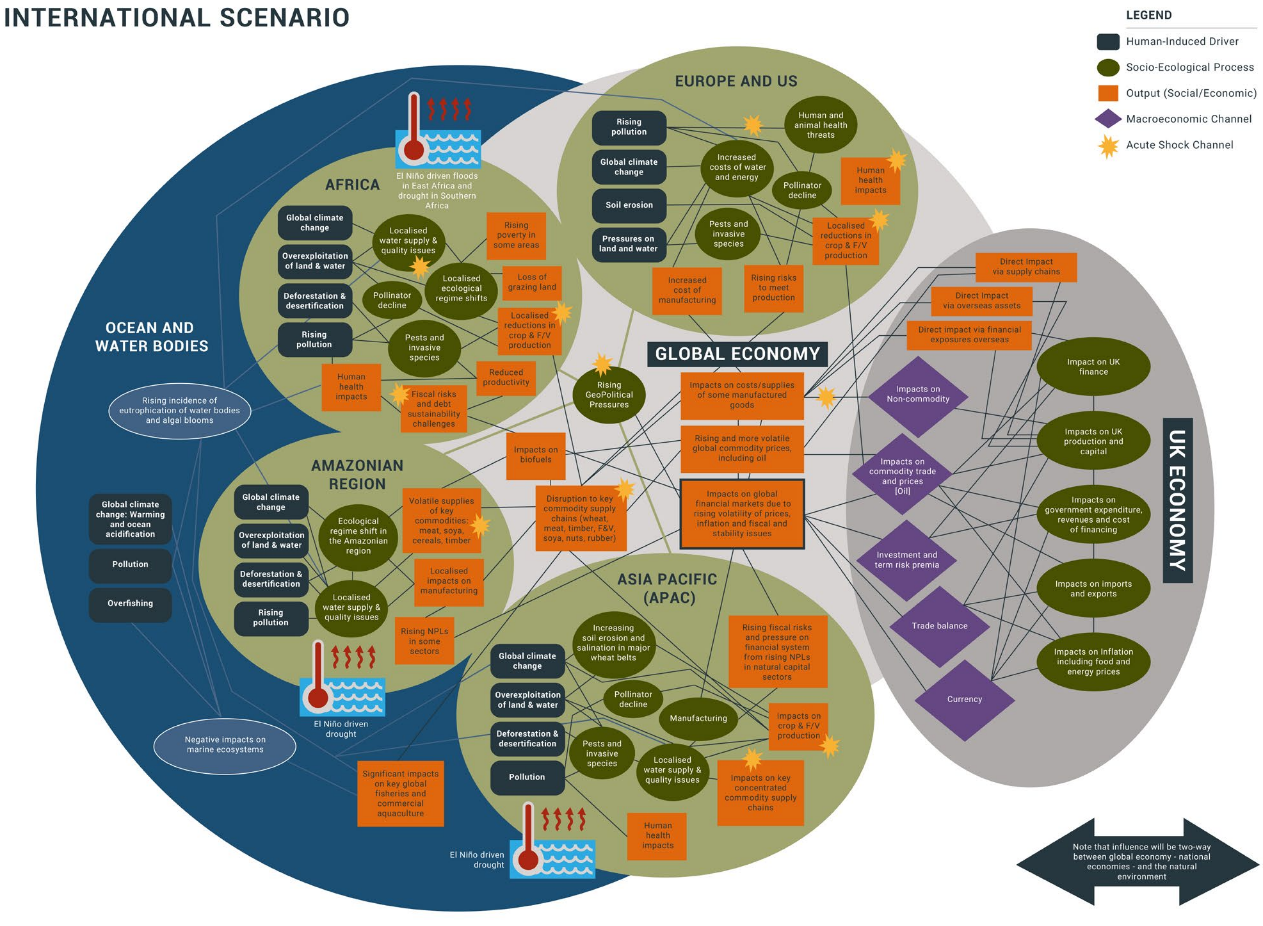


Figure 15. *International supply chain disruption scenario (Avery, Ranger, and Oliver 2024).*

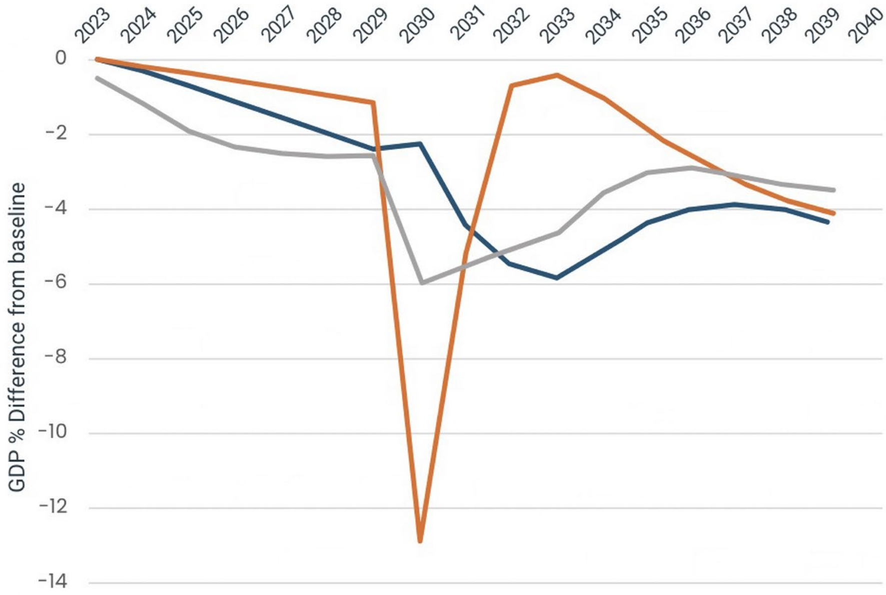


Figure 16. *Projected UK GDP impacts of the three nature-related risk scenarios from Avery, Ranger, and Oliver (2024). The orange line represents the health scenario, the grey line corresponds to the domestic natural capital scenario and the blue line depicts the international supply chains scenario.*

Figure 16 clearly demonstrates the potential significant financial and economic materiality of nature-related risks to the UK economy. The international supply chain scenario – which simulates purely the impact of an international supply chain shock related to environmental degradation on the UK – could result in up to a 6% reduction in GDP versus the baseline within the next 10 years. This damage persists for multiple years due to the long recovery times of international trade and worsens over time following gradual environmental damage. When combined with climate change, the losses could be even greater. The study also evaluated the impacts on other countries around the world and found similar or larger effects, particularly in emerging and developing economies.

Based on this evidence, we can conclude the following:

- Nature-related risks are financially material to the UK economy and financial sector, with at least half of these risks linked to international supply chains.
- Under a scenario of a major international supply chain shock related to natural capital degradation globally, the UK GDP could experience a 6% loss relative to baseline growth over the next decade.
- UK banks, particularly international banks and those with significant exposure to agriculture and manufacturing, are highly vulnerable to these risks.

3.4 CASE STUDY 4: ENERGY – Green ammonia for resilience

Decarbonising the UK economy requires scaling up renewable energy supplies as well as alternative green fuels production, either domestically or from abroad. One widely discussed green fuels is green ammonia – ammonia produced using renewable energy sources. Green ammonia is made by first using hydrogen from water electrolysis and nitrogen separated from the air. These are fed into the Haber-Bosch process, where hydrogen and nitrogen are reacted together at high temperatures and pressures to produce green ammonia (NH_3). All the energy required for these processes are powered by renewable energy.

There are four main applications for green ammonia in the UK economy:

- **Fertiliser:** Ammonia is commonly used in fertiliser production. The push to decarbonise agriculture is expected to drive increasing demand for green fertiliser.
- **Energy storage:** Because ammonia can be easily stored in bulk, it is a suitable chemical for renewable energy storage. This is particularly useful for covering long periods where renewable energy systems in the UK (especially wind) might not be able to generate enough energy.
- **Zero-carbon fuel:** Green ammonia has significant potential as a green fuel for maritime transport to decarbonise the sector.
- **Hydrogen carrier**: Green hydrogen is another proposed green energy source for various applications. However, importing green hydrogen over long distances will likely require first transforming hydrogen into ammonia, transporting it in that form, and then 'cracking' and purifying it into hydrogen gas.

Although the scale of future demand for green ammonia in the UK is uncertain, current transition pathways, including the UK's *Net Zero Strategy* (House of Commons 2022) and recommendations from the Royal Society (The Royal Society 2021), suggest that a market for it will likely emerge, especially after 2030. Green ammonia can enhance the resilience of the UK energy system to weather-related and other shocks as the country transitions towards growing dependence on renewables. The UK hydrogen economy roadmap (2023)[18] also sets the ambition for widespread hydrogen use in industry and power generation, with some use in transport by the late 2020s, and aims to expand it further to a 'full range of end uses including across industry; power system; shipping and aviation; potential gas grid conversion' (Department for Energy Security & Net Zero 2023, 11).

As the UK shifts its dependencies from traditional fossil fuel-related supply chains to these new green supply chains, it will be critical to reassess the implications for UK systemic resilience. While reducing the use of energy and materials from fossil fuels has the advantage of decreasing dependence on more unstable oil-rich countries, the new green supply chains will introduce entirely new exposures and dependences. Yet, limited attention has been accorded to new green fuels related to the energy transition. As such, this case study focuses on green ammonia and its role in building resilience in the future UK energy system.

To ensure a resilient UK future energy system, large-scale storage is required due to the high penetration of renewable energy sources, which are inherently intermittent. A Royal Society report estimated that 60–100 TWh of energy storage will be needed by 2050 – over 1,000 times the current capacity of pumped hydro in the UK (The Royal Society 2023). An evaluation of different options, including domestic ammonia production for storage, found that long-term energy storage would likely be based on storing hydrogen in salt caverns. However, the report did not consider future green ammonia imports. For the case of green ammonia, from a purely cost-competitiveness perspective,

18 The UK vision for domestic hydrogen production has gradually expanded since the 2021 UK Hydrogen Strategy. The government's ambition is to 'have up to 10 GW of low carbon hydrogen production capacity by 2030 (…) and at least half of this capacity comprising electrolytic or "green" hydrogen.' In line with this ambition, the government supports 11 new green hydrogen projects across the country (Department for Energy Security & Net Zero 2023).

importing green ammonia is likely to be considerably cheaper than producing it domestically without large government subsidies. For instance, the Royal Society report (2023) estimated that domestic green ammonia production would cost around $760 per tonne in 2050.

Based on modelling of future green ammonia production globally, and the cost of transporting it to the UK – both conducted at the University of Oxford – we can evaluate which countries are most suitable for importing green ammonia to the UK (Verschuur et al. 2024)yet there are conflicting ambitions for where global production, transport and fuelling infrastructure will be located. Here, we develop a spatial modelling framework to quantify the cost-optimal fuel supply to decarbonise shipping in 2050 using green ammonia. We find that the demand for green ammonia by 2050 could be three to four times the current (grey. This assessment is based on two scenarios of future cost declines of various energy production costs (a steep cost decline and a moderately steep cost decline), assumptions about future cost of capital, and detailed weather profiles at locations globally (see Appendix).

Figure 17 shows initial findings on the top 30 countries with the lowest levelised cost of supplying green ammonia to the UK in 2050. Levelised cost refers to all the costs involved in producing green ammonia, transporting it to the exporting port, shipping it to the UK, and storing it at UK ports.

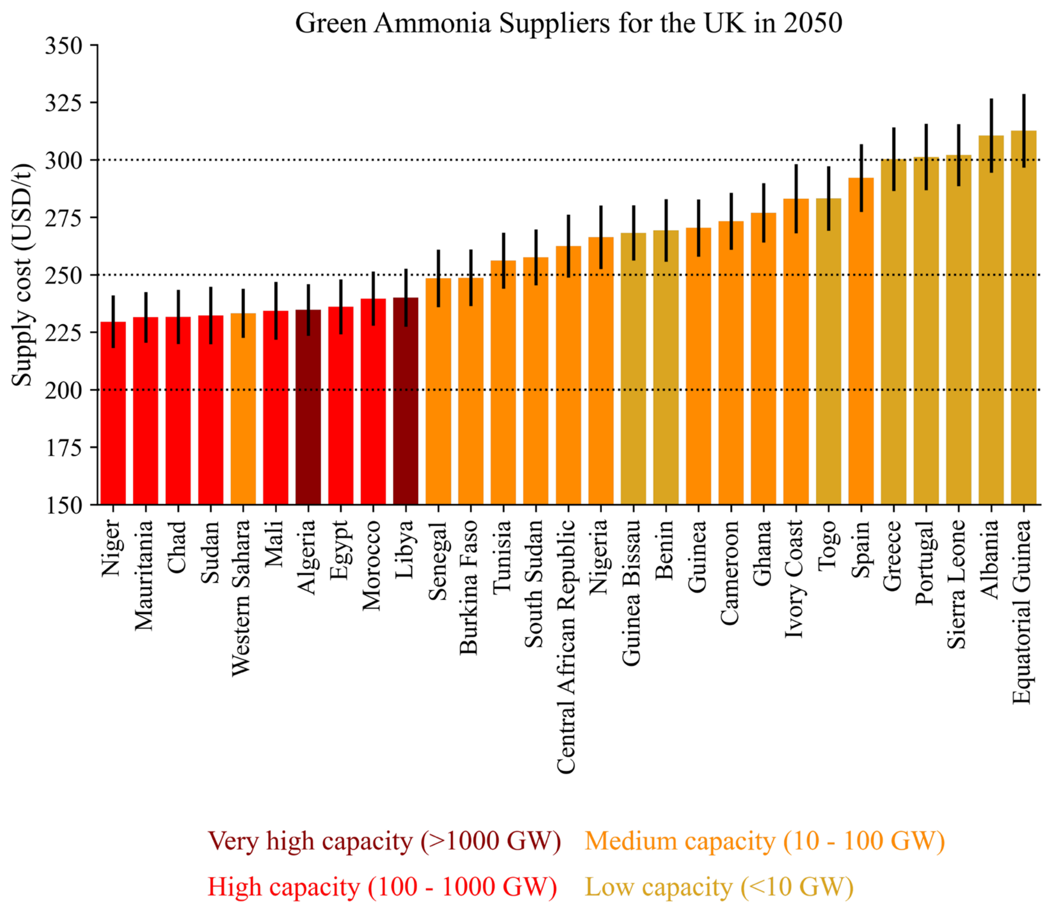


Figure 17. *Top 30 lowest-cost suppliers of green ammonia in 2050 with their green ammonia production capacity. The size of the bar shows the average of the two scenarios, while the error bar indicates the range across the two scenarios.*

Most of the suitable sourcing countries are located in Northern or Western Africa due to their strong solar potential, with North and Saharan African countries having the lowest costs. Algeria and Libya, in addition to having low supply costs, also have a high capacity for green ammonia production. However, as can be observed in Figure 17, cost differences across countries are relatively small in 2050. It should be noted that these costs are indicative (and fairly optimistic), as many assumptions are involved in long-term energy price forecasting. For instance, the cost of capital may be higher in some of these top 30 countries (e.g. Niger, Sudan) compared to others (e.g. Algeria, Morocco), which can cause shift in the relative cost competitiveness of these supplying countries. While regional cost differences are included in this analysis, differences in costs of capital are not explicitly included. Moreover, political, financial and governance factors that shape decision-making of energy sourcing are not considered here but could make some countries more or less likely to become major green ammonia suppliers.

Drawing on these findings, it becomes apparent that the UK can establish a diversified supply of green ammonia at a price much below the cost of domestic green ammonia production. According to the recent study (Palazzi et al. 2024), imported green ammonia could serve as a suitable source of large-scale energy storage, with the added benefits of being sourced from a variety of countries and having broad industrial application potential (for fertiliser or industrial use). Green ammonia can provide energy during periods of low renewable energy at costs similar to the optimal option identified in the Royal Society report (hydrogen storage) and should be considered a feasible option to complement other long-duration storage options.

Three early conclusions derive from this analysis :

1. Green ammonia could be considered a long-term option for improving the resilience of the UK energy system under high renewable energy penetration, which is expected by 2035.
2. The likely sources of green ammonia could include a large number of countries, which is indicative of good prospects for supply chain diversification at relatively minor additional costs (at least based on production costs alone). This contrasts with the existing fossil-fuel supply, where supply diversification is more challenging and comes at a higher cost.
3. The top 30 supplier countries are concentrated in Africa and include countries with ongoing fragility and unfavourable investment climates. While the modelled scenario assumes a possibility of reducing the cost of capital in these contexts, further analysis is needed on how this could be achieved, particularly given that investment would need to be made before 2050. For policymakers, this raises questions about how to engage with these countries over the coming decades to help build stability and ensure that countries can take advantage of the potential revenue opportunities from green ammonia, while securing stable supply chains of green ammonia for the UK.

3.5 CONCLUSIONS

The four case studies, discussed above, demonstrate how the nature of risks is changing, with climate and environmental change introducing risks distinct from those experienced in the past. These include:

- **Potential for abrupt shifts**: Rising risks associated with the erosion of natural assets and ecosystem services, including the potential to reach local ecological tipping points that could lead to abrupt and severe impacts on global supply chains.
- **Evolving dependencies and risks**: The UK's evolving domestic energy and food systems are shaped by climate change, domestic net zero and adaptation policies, and consequently by changing patterns of dependence on overseas partners. For example, the shift away from dependence on oil-producing countries and towards new suppliers of critical minerals and green ammonia, including across Africa.

- **Exposure to global shocks**: Increasing exposure to global cascading and complex risks due to the more interconnected and interdependent nature of the economy, as illustrated by the case study of shocks to ports and marine chokepoints.
- **Increased risk of highly correlated shocks across countries and sectors:** Compounding climate and nature-related risks, and the interaction with non-climate shocks (e.g. trade restrictions, conflict), leading to systemic-level impacts across countries and sectors that could severely disrupt the global economy.

These case studies highlight how analytics can be used to assess risks across systems and supply chains. They also underscore how the UK and global monitoring, risk assessment and early warning systems need to tackle the emerging challenges, as well as the potential importance of early planning, engagement and investment overseas to mitigate risks and secure UK systemic resilience. Recent events also reminds us that these shocks do not occur in isolation. The COVID-19 pandemic and Ukraine crisis demonstrate that the UK economy can be hit by more than one event simultaneously, with compounding consequences leading to more severe impacts. Several studies, including those by the World Economic Forum and the UN Office for Disaster Risk Reduction, have warned that the risk of so-called polycrises is increasing as a result of our interconnected economies, the growing threats of climate change and environmental degradation. The amplification effect of multiple crises is illustrated by the food case study above. It is essential that hazards, including climate-related and non-climate related ones (e.g. trade restrictions, conflict, demographic and technological changes) are not treated in isolation within our risk monitoring and management systems. The following section reviews current actions to strengthen resilience to TCRs.

4. REDUCING TRANSNATIONAL CLIMATE (AND ENVIRONMENTAL) RISKS

The world is falling behind in achieving the SDGs, and the evidence – including that presented in this report – suggests this shortfall may undermine global systemic resilience and increase transnational risks to the UK. Interventions to mitigate and alleviate cascading risks are intricate given the complexity, multiple drivers and scales over which these risks operate. The challenge of determining the most effective way of intervention to build systemic resilience was highlighted by the Cabinet Office: ‘*The challenge of where to place investment in the risk cycle is one that affects the public and private sectors alike*’ (Cabinet Office 2021).This section reviews the UK’s current policy landscape for managing transnational risks and assesses opportunities to build systemic resilience in three key areas: data, finance and governance, and regulation.

4.1 POLICY: Review of current UK policy frameworks

This section provides a rapid review of the UK’s policy landscape since the publication of the *Integrated Review of Security, Defence, Development and Foreign Policy* in 2022, assessing how it addresses Transnational Climate Risks (**TCRs).** The analysis also draws upon the most recent Climate Change Committee and Select Committee gap assessments. Table 2 highlights that recent government policies widely recognise the pertinence of TCRs to the UK across sectors, including several new initiatives, such as research, policy, training and evaluation centres working on TCRs and their implications for the UK, including SitCen (2021), the UK Resilience Forum (UKRF, 2021) and the UK Resilience Academy. The UK’s 2023 Third National Adaptation Programme also includes several policy actions addressing international dimensions of climate risks.

Current policy frameworks include actions to build domestic systemic resilience to TCRs, as well as policies to tackle the root causes of vulnerability through investing in strengthening resilience and adaptation overseas, both bilaterally and through the UK’s relationships with multilateral actors. In March 2024, the Climate Change Committee released a rapid review of government progress against the actions set out in the Third Climate Change Risk Assessment to manage the international risks of climate change (Figure 18). Table 3 summarises some key findings relevant to the themes discussed in this report – infrastructure, supply chains, food, finance and trade. This reveals some significant ongoing activities across government, particularly on supply chain resilience (ID07), but also indicates that many areas remain unaddressed or only minimally addressed. Notably, the dimension of risk multiplication from interacting and cascading climate risks (ID10) – the focus of this report – was assessed as ‘recognised’ but not addressed in current policy. A fuller assessment of the state of implementation of the wider range of policies set out in Table 2 is beyond the scope of this report. However, based on the Climate Change Committee assessment, the UK still has significant progress to make in implementation and gaps to address in its policy and finance frameworks, as outlined in this report.

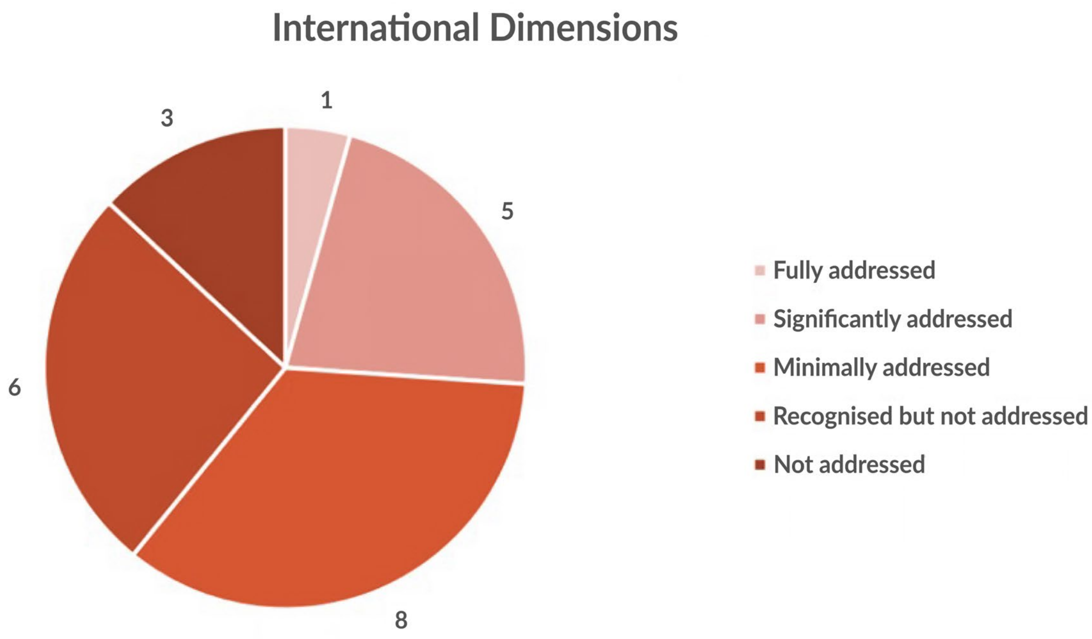


Figure 18. *Distribution of actions (categorised by evaluation score, related to International Dimensions sector risks).*

Source: ADAS for the CCC (2024).

The following sections review progress and gaps in key policy areas relevant to UK systemic resilience to TCRs: finance (both mobilising finance in EMDEs and aligning financial flows with resilience), data, trade policy and supply chains, regulation and risk governance. While many other areas of policy are also highly relevant to managing TCRs and the international dimensions of climate change risks to the UK, we focus here on those with direct relevance to infrastructure and supply chains.

Table 2. UK policy frameworks for managing TCRs

Policy Document	Acknowledgement /Consideration of TCRs and UK impacts	Adaptation commitments (EMDEs, financial)	Strategies (relevant to TCRs and UK systemic resilience)	Governance/ Legislation/ Regulation (relevant to TCRs)	Research / Innovation (relevant to TCRs and adaptation in EMDEs)
Resilience for the Future: The United Kingdom's Critical Minerals Strategy (HM Government 2022)	None	None	'**Diversify supply** across the world so it becomes more resilient as demand grows; Support UK companies to participate overseas in diversified responsible and transparent supply chains.'	'Boost global **environmental, social and governance (ESG) performance**, reducing vulnerability to disruption and levelling the playing field for responsible businesses.'	'Carry out cutting-edge research and development to solve the challenges in critical minerals supply chains.'
Powering Up Britain: Energy Security Plan (HM Government 2023e)	None	None	Increased gas storage; supply chain diversification. 'Beyond the EU we work with strong trusted partners and allies including through our **Strategic Energy Dialogues** to help tackle national and global energy challenges.'		None
Critical Imports and Supply Chains Strategy (HM Government 2024)	'Climate change presents one of the most significant global trends facing the world economy in the years to come. Government recognises the need to increase the resilience of supply chains to climate change. Therefore, we are taking forward work to understand the implications for our supply of critical goods and to develop responses based on both adapting to and mitigating the effects of a changing climate.'	None	'Making the UK government a centre of excellence for **supply chain analysis and risk assessment**'; 'Building the UK's **response to global supply chain shocks**'; 'Ensuring the UK can **adapt to long-term trends.'**	'The UK continues to work ever more closely with allies and partners in multilateral fora to promote and defend stable global trading rules which, builds resilience in the world's most critical collective supply chains, supports low and middle-income countries and fosters predictability for businesses. We have continued this work through the G7, G20, and the World Trade Organization (WTO).'	'Employ cutting-edge techniques to better understand how our critical supply chains will evolve in the future, working with the Government Office for Science to map future supply chains scenarios.' 'New technologies have the potential for government and business to improve the management of critical supply chains. The UK's Digital Catapult has established the Made Smarter Digital Supply Chain Hub. This is a £25 million national programme funded through Innovate UK working to advance and accelerate the innovation and adoption of digital technology in UK supply chains.'
National Risk Register (2023 edition). (HM Government 2023d)	Includes climate risks and humanitarian costs abroad, no mention of their impact to UK resilience.	N/A	N/A	N/A	N/A
The UK Government Resilience Framework (Cabinet Office 2023)	'The UK's international connections are vectors for both risk and resilience. Risks do not operate in silos, but are interconnected like our economy, environment and society.' 'For the UK, resilience is not simply a matter of homeland security; this is a globally-oriented maritime trading nation without a large continental hinterland, and that must shape our strategic approach.'	None	'The UK Government will continue to **show leadership on resilience** through international fora and through strong bilateral relationships (…). This will include **providing support to international partners** to build their own resilience, and working together to tackle risks before they manifest.'	'The UK Government will introduce **standards on resilience** and develop an action plan to deliver these across the private sector, where these *do not* already exist, to give a clear benchmark on what 'good' looks like for resilience. These standards on resilience will be non-statutory, and adjusted to take into account the unique sector landscapes, priorities, needs, and interlinkages with other sectors.'	'The UK Government commits to continuing to build partnerships between the public and private sector to improve our collective resilience and to identify opportunities for innovation.'

The Third National Adaptation Programme (NAP3) and the Fourth Strategy for Climate Adaptation Reporting (HM Government 2023f)	'These risks can impact across borders and affect supply to UK sectors, including energy and food. CCRA3 highlighted the potential security implications from climate change, such as impacts on global supply chains that cross international boundaries and exacerbation of violent conflict and migration. This is the first time that the NAP has dedicated a chapter to addressing them.'	'(…) **tripling of adaptation funding** through Official Development Assistance to £1.5bn in 2025 (see International Climate Finance Strategy).'	N/A (document directs to other policies)	N/A (document directs to other policies)	'Defra will: • support world-leading science and evidence, such as the **UK Climate Projections;** • jointly fund a forthcoming £15 million UK Research and Innovation /Defra programme to support the research and innovation needed to deliver adaptation action.'
Global Britain in a competitive age: The Integrated Review of Security, Defence, Development and Foreign Policy (HM Government 2021)	'The UK's resilience is intertwined with global resilience. The transnational nature of many challenges, from climate change and biodiversity loss to biosecurity and energy security crises, means that no single government can address them alone.' 'We will improve our own ability to anticipate, prevent, prepare for, respond to and recover from risks – as well as that of our allies and partners, recognising the closely interconnected nature of our world. And we will prioritise efforts to tackle climate change and biodiversity loss.'	'From 2021 to 2026, the UK will commit **£11.6bn to International Climate Finance**, including **£3bn for nature financing**.'	'Our second goal is to **tackle climate change and biodiversity loss**, which require immediate and concerted action worldwide. This will be the **UK's foremost international priority**, building on our domestic commitment to reach net zero by 2050.' 'We will protect and restore nature, including by driving support for ambitious new global targets for nature at the UN Biodiversity Conference (CBD COP15) in Kunming in 2021, to improve ecosystem resilience and species recovery, and to tackle the causes of nature loss.' 'We will convene the **Forest, Agriculture and Commodity Trade Dialogue**, bringing together the world's largest producer and consumer countries of forest-risk commodities to agree collaborative actions that will protect forests whilst promoting trade and development.' 'We will partner with the **African Union** on climate and biodiversity, global health security, free trade, crisis management (…); **Jordan and Oman** – (…) We will look to deepen these links to become one of the region's primary trade and investment partners and build support for our climate objectives; We will enhance our work promoting greater economic, societal and environmental resilience, including in key countries such as **Egypt**; support work on sustainable growth and climate change with **Iraq** and **Morocco** (…); we will deepen our ties with **Brazil** and **Mexico**, strengthening partnerships on trade, innovation, climate, security.'	Limited focus on governance and regulation related to TCRs. 'we will combine our work on maritime security, the environment and trade. Fundamental to this will be an absolute commitment to upholding the UN Convention on the Law of the Sea in all its dimensions, as an essential enabler of global prosperity, security and a healthy planet.'	Research and innovation constitute a key component of the overall strategy, but this is focused on national security: 'Sustaining strategic advantage through science and technology: we will incorporate S&T as an integral element of our national security and international policy, fortifying the position of the UK as a global S&T and responsible cyber power.' 'The Government has committed to increasing economy-wide investment in R&D to 2.4% of GDP by 2027, including through inward investment. Through the R&D roadmap, we will ensure that public R&D spending continues to support discovery research, and increase investment in applied research, development and implementation.' 'Our aim is to become the world's leading centre for green technology, finance and wind energy, mobilising £12 billion of government investment and much more private investment to create and support up to 250,000 jobs across the UK. We will increase support for net zero innovation and new industries.'

Integrated Review Refresh 2023. Responding to a more contested and volatile world (HM Government 2023b)	'IR2023 responds to the multiplying effects of overlapping transnational challenges, which are compounding wider global instability. (…) climate change and biodiversity loss are important multipliers of other global threats, and are guaranteed to continue to worsen over the next decade (…). At home, these transnational challenges test the UK's own resilience.' '(…) the UK must be prepared to deal with global trends and events that will exert shaping forces on our national life, but that we cannot always control or prevent at source. These will range from: well understood transnational challenges, such as mass migration and climate change.' 'In parallel we will continue to strengthen the UK's resilience to the range of interlinked risks associated with climate change and environmental damage. This is firmly linked to the international agenda on climate change, biodiversity loss and sustainable development outlined in pillar one, as the UK's resilience to these risks requires greater global resilience.'	'Through Room to Run, we have made a new UK guarantee to the African Development Bank that is expected to unlock up to **$2 billion of new financing** for climate adaptation projects.' 'Delivering clean, green infrastructure and investment, through British Investment Partnerships, UK contributions to the $600 billion G7 Partnership for Global Infrastructure and Investment, and by leveraging the support of capital markets and the private sector.' 'In delivering our international development offer, we will go beyond ODA to use all of our levers in support of development outcomes. This includes working through international institutions, sharing our expertise – including through new UK Centres of Expertise in technology, illicit finance, and green cities and infrastructure – and leveraging London's position as a leading financial centre, such as through British Investment Partnerships' initiatives to mobilise **£8 billion financing per year by 2025**.'	'The UK's first thematic priority remains tackling **climate change, environmental damage and biodiversity loss**, given the urgency of making progress before 2030.' 'With **Malaysia**, the **Philippines, Thailand** and **Vietnam**, strengthening our partnerships across shared priorities in trade and investment, climate change (…); Deepening our engagement with **Pacific Island countries** and regional resilience in the Pacific, supporting the 2050 Strategy for the Blue Pacific Continent (…); the UK's approach in **Africa** will continue to be defined by a greater appreciation of the needs and perspectives of key partners across the continent, focusing on mutually beneficial development, security and defence partnerships, and support for clean infrastructure and climate adaptation.'	Limited focus on governance and regulation related to TCRs. 'Reforming and greening the global financial system to ensure the International Financial Institutions – in particular the multilateral development banks and the International Monetary Fund (IMF) – and capital markets are better equipped to meet the needs of developing countries in dealing with the economic, debt, climate and nature crises.'	Research and innovation commitments remain focused on national security and the domestic economy. 'Leading a global campaign on 'open science for global resilience', making the case for a secure, collaborative approach to science that ensures low- and middle-income countries have access to knowledge and resources that can support improved resilience.'

Together for People and Planet. UK International Climate Finance Strategy (HM Government 2023g)	No mention of impacts to UK or UK resilience	'The UK and other developed countries have committed through the UNFCCC to a collective target of providing and **mobilising US$100 billion climate finance a year** for developing countries from public and private sources.' '**£120 million of new support for DRF**' [Disaster Risk Finance]. 'Launched at COP26 in Glasgow in 2021, the **£27.5m Urban Climate Action Programme** (UCAP) is working with cities in developing countries to implement low-carbon urban infrastructure projects.'	'**Sustainable Cities, Infrastructure and Transport**: With 68% of the world population projected to live in urban areas by 2050 and cities accounting for 75% of global CO2 emissions today, (…), we will support low carbon, green and resilient urbanisation in order to promote sustainable and accessible cities, along with enabling access to clean and reliable infrastructure, including by attracting investment across the transport, digital, built environment, water and waste sectors.' 'Scaling up and targeting public and private investment to protect more people from the impacts of disasters including through **disaster risk finance** (DRF) and **development insurance** and **climate resilient debt clauses** (CRDCs) which automatically pause debt repayments when a climate shock or natural disaster hits.' 'British Investment Partnerships building stronger, more transparent economic partnerships which will facilitate the **development of high quality, clean, reliable infrastructure** to support green transitions and narrow the infrastructure investment gap in low- and middle-income countries.'	'Supporting city and infrastructure governance institutions to become more accountable, effective, and capable. This will support them in being better able to plan and attract investment in sustainable, low carbon and climate resilient infrastructure and urban development that supports economic growth and development.' 'The UK will continue to work with partners to shape the global response to proposals for international climate finance architecture reform, especially the **Bridgetown Initiative** promoted by the Prime Minister of Barbados, the **World Bank evolution roadmap**, and the **G20 MDB Capital Adequacy Framework Review**. We will press internationally for key policy and regulatory reforms following progress at COP26.' '**Forest Governance Markets and Climate (FGMC)** is a 12-year programme that brings together trade policy with development assistance to improve global forestry business practices. It promotes policies, incentives and business standards that secure rights and rule of law, while protecting livelihoods linked to the forest sector, promoting growth and curbing deforestation.'	'…We will have a strong focus on RD&D and will step up our investment in cutting-edge science, technology, and innovation…' The Climate and Resilience Framework Programme (CLARE): '(…) supporting the Adaptation Research Alliance to promote action-oriented research to inform effective adaptation to reduce the risks from climate change, particularly for countries and communities that are most vulnerable.'
2030 Strategic Framework for International Climate and Nature Action (HM Government 2023a)	'Climate change will cause more frequent and severe weather events, leading to an increased likelihood of global supply chain disruption, and will lead to longer-term shifts in economic activity and trade. At the same time, nature loss can deplete natural resources and significantly shift supply and demand for traded goods and services. As a highly trade-dependent economy, the UK is particularly at risk from instability in trade.'	'We will continue to press developed countries to double adaptation finance by 2025 (on 2019 levels) to $40 billion.' '(…) our commitment to invest at least **£3 billion** of the UK's International Climate Finance between 2021 and 2026 to tackle climate change through **the protection, restoration and sustainable management of nature**.'	'1. **Transition to clean technologies** and sustainable practices; 2. **Build resilience and adapt** to climate impacts; 3. **Increase protection, conservation and restoration of nature**; 4. **Strengthen international agreements and cooperation** to accelerate delivery of climate and nature commitments; 5. **Align global financial flows** with a net zero, climate resilient and nature positive future; 6. **Shift trade and investment rules and patterns** to support the transition to a climate and nature positive future.'	'Mainstreaming climate and nature into global governance institutions.' 'Advocating for integrated approaches to climate and nature under multilateral frameworks and environmental agreements. We will build on commitments in the Leaders' Pledge for Nature, and work with future Rio Convention and G7/G20 Presidencies.' 'Effectively implementing regulatory frameworks and managing financial risk across the economy, empowering regulators such as the Bank of England.'	'Science, innovation and technology' mentioned as a key lever for the realisation of the 6-point strategy.

International development in a contested world: ending extreme poverty and tackling climate change. A White Paper on International Development (FCDO 2023)	'The impacts of climate change and nature loss are being felt by everyone, everywhere.'	'(…) the UK has announced **guarantees that will unlock more than $6 billion of additional multilateral development bank (MDB) finance** for African, Asian, and Pacific countries.' 'We will maintain a balance between adaptation and mitigation, with at least £1.5 billion of International Climate **Finance (ICF) spend on adaptation** in 2025.' 'We will deliver on our **commitment to provide £11.6 billion in international climate finance** between 2021 to 2022 and 2025 to 2026, ensuring a balance between adaptation and mitigation and including **at least £3 billion to protect and restore nature**.'	'We will help **secure an ambitious new global climate finance goal in 2024** through playing a constructive role in international climate negotiation processes, balancing mitigation and adaptation funding. This includes a **nature finance component in support of the Global Biodiversity Framework** .' 'We will advance action on climate adaptation by **building capacity, planning and finance at national and international levels**, transforming priority sectors and systems, and working with effective nature-based solutions.' 'We will **improve the climate resilience and prosperity of vulnerable coastal communities and SIDS**. We will support a more sustainable and inclusive management of their marine environment and coastal resources through UK Government financed programmes.' 'We also played a leading role in the historic **Kunming-Montreal Global Biodiversity Framework** (COP 15, 2022) being agreed, to halt and reverse the destruction of nature.' 'Delivering the **Global Biodiversity Framework** will mean that at least 30% of land and ocean is protected globally by 2030, and 30% of degraded ecosystems are under restoration.' 'We will protect the marine environment by addressing marine biodiversity, pollution, climate change, and sustainable seafood, including using the **UK's Blue Planet Fund.**'	'There is an opportunity to further deploy the UK's green finance strength and expertise internationally, greening investing practices. The UK is already helping countries to develop investible national climate and nature plans to attract international capital, putting in place plans to transition to low carbon investment and **supporting the disclosure of the climate and nature impact of investments**. **We support partner countries to develop finance systems and build their regulatory and tracking capability**'	Multiple research and innovation commitments, including: 'We will support major international research collaborations (…) that seek to harness new solutions and cutting-edge technologies to solve the global challenges of securing food, nutrition and health security for all in the face of a changing climate.' 'We will (…) leverage the science expertise and leadership in UK institutions such as the Met Office, to better predict the changing climate, and use information to support millions of poor farmers and communities in 30 countries.' 'We will test and use the opportunities provided by satellite data and advanced analytical techniques. These include the use of AI to allow rapid identification of conflict flashpoints, respond more pre-emptively to extreme weather events, and enable faster responses to humanitarian emergencies.' 'We will establish a new co-ordinated UK R&D initiative for international nature and invest in water and ecosystems research to test and scale innovations that build resilience to climate change.'

Mobilising Green Investment. 2023 Green Finance Strategy (HM Government 2023c)	'We also need to tackle the risks from climate change and environmental degradation. From increasingly frequent and severe weather events causing damage to infrastructure and supply chains, to changing consumer expectations and preferences shifting demand for certain products and services, companies and their investors need the right policies in place to support them in managing these risks and avoiding stranded assets. Acting now is also important to minimise the fiscal risks of the transition and maximise the growth opportunities.'	'UK will support emerging and developing economies (EMDEs) to grow sustainably while creating opportunities for shared prosperity. Utilising a range of levers, including delivering on our commitment to provide **£11.6 billion in International Climate Finance (ICF)** between 2021–22 and 2025–26.' 'The International Development Strategy set out our commitment to ensure our bilateral ODA becomes 'nature positive', aligning with the Kunming-Montreal Global Biodiversity Framework and the international goal to halt and reverse biodiversity loss by 2030.' 'UK will double International Climate Finance (ICF) and as part of this triple our funding for adaptation from 500 million in 2019 to 1.5 billion in 2025' 'The UK's £100 million **Biodiverse Landscapes Fund (BLF)** will have a strong focus on leveraging private capital to protect biodiversity and reduce poverty in six global biodiverse hotspots across three continents' 'The UK's £500 million **Blue Planet Fund** (BPF) supports EMDEs to reduce poverty, protect and sustainably manage their marine resources and address human-generated threats.'	'We will deliver a **UK Green Taxonomy** – a tool to provide investors with definitions of which economic activities should be labelled as green.' '(…) launching our Financial Services Centre of Expertise. The Centre will leverage the UK's strengths to **provide tailored support on financial market development in EMDEs** with a heavy emphasis on green finance, we expect the Centre to be fully operational by 2025.' 'Our aim is **to facilitate EMDEs to develop net zero aligned financial systems**. This will enable them to address data gaps, access international green finance flows, avoid a proliferation of standards and practices, and better enable the UK financial sector to support the development of, and provide capital to, net zero transitions globally.' 'in 2022 the UK – in collaboration with Ecuador, Gabon, and the Maldives – set out a political vision for bridging the global nature finance gap through the **10 Point Plan for Financing Biodiversity**. The Plan presents a clear pathway for bridging the global nature finance gap by defining the role of all sources of finance, with a particular focus on how international public finance can support EMDEs to accelerate the transition to become nature positive.' 'The UK is taking a leading role, including by **supporting the Bridgetown Agenda** and **operationalisation of the IMF's Resilience and Sustainability Trust**. The UK is calling for the Multilateral Development Banks (MDBs) to unlock billions of dollars in new lending by implementing the recommendations of the G20 Review of MDBs' Capital Adequacy Framework. We are **championing the use of Climate Resilient Debt Clauses**, with UK Export Finance becoming the first bilateral Export Credit Agency to offer these. And we are **supporting the Canada-led Global Carbon Pricing Challenge** and its aim to triple the coverage of carbon pricing globally, which is critical for greening finance flows.'	'We passed the landmark Environment Act 2021, putting environmental goals, such as reversing the decline in biodiversity, on a statutory footing.' 'commitments on finance made in the landmark Kunming-Montreal Global Biodiversity Framework agreed at the UN Convention on Biological Diversity COP 15 in December 2022.' '2020: UK government was the first G7 country to commit to mandatory TCFD [Taskforce on Climate-related Financial Disclosures] reporting, and published a roadmap towards mandatory climate-related disclosure.' 'We will work with the Financial Conduct Authority, Financial Reporting Council and the Pensions Regulator to review the regulatory framework for the effective stewardship that is crucial to climate and environmental oversight.' 'We will work closely with financial regulators – such as the Bank of England, Financial Conduct Authority, Financial Reporting Council and The Pensions Regulator – and the environmental regulator in England, the Environment Agency, to ensure that the UK's regulatory framework supports the growth of green finance.'	Multiple research and innovation commitments, including: 'The UK is also pioneering breakthrough technologies and investing in world class data and analytics, for example through the Centre for Greening Finance and Investment, a research consortium led by the University of Oxford and funded by UK Research & Innovation.' 'The UK government, working with the CCC, is scoping research requirements in adaptation investment needs. The analysis will expand on the CCC's 2023 report on adaptation finance to improve the evidence base, and findings will be published in the fourth Climate Change Risk Assessment (CCRA4), due for publication in 2027.' 'the UK is working with the Climate Policy Initiative (CPI) to map the mobilisation of finance flows through the UK to EMDEs, including to understand data gaps and how tracking and reporting of international flows could be improved.' 'We are working with the Ecosystems Knowledge Network and Green Finance Institute (GFI) to publicise and share cases studies and learning from the Natural Environment Investment Readiness Fund (NEIRF).' 'The Government will also continue working to improve the supply, quality and comparability of climate and nature related financial data, globally.'

Table 3. Brief Summary of Findings of Climate Change Committee (2024) Rapid Assessment of Progress for those Risks most relevant to this study (ID10,8,7,6,2,1)

Risk	England Magnitude by 2050	CCRA Actions (in brief)	Summary of Responses from Government (CCC 2024)	Evaluation Score (CCC 2024)	Risk and Action Owner
ID10: Risk multiplication from the interactions and cascades of named risks across systems and geographies	High	Further investigation of economic evidence of transformational adaptation is needed	FCDO will co-chair Adaptation Research Alliance; Defra engaging with international partners via OECD including on measuring progress	Recognised but not addressed	FCDO Defra Cabinet Office
ID08: Risk to the UK finance sector from climate change overseas	Medium	Address global green finance gap and uncertainty over national and international climate policy as a key factor in this gap	Push for global adoption of ISSB; support transition plan disclosure; work with international partners to support interoperability and standardisation; Green Finance Strategy	Minimally Addressed	HMT
ID07: Risks from climate change on international trade routes	Medium	Policies that focus on building further resilience as a design feature of trade	DBT to publish new strategy; DBT analysis shared; policy and interventions to guide public and private orgs; engagement with business; incorporate climate intro critical supply chain stress tests by end of 2024 and support remedial action; support partners to undertake sustainable infrastructure; encourage insurance solutions and improve forecasting and infrastructure investment; work with industry to manage potential disruption to supply chains due to climate.	Significantly Addressed	DBT
ID06: Opportunities from climate change on international trade routes	High	Enabling actions from Government to realise economic benefits	Supply chain resilience framework; DBT working to increased shared understanding of supply chain risks and opportunities, e.g. Global Supply Chains Intelligence Programme	Minimally Addressed	FCDO and DBT
ID02: Opportunities for UK food availability and exports from climate impacts overseas	Low	Ensuring access to broad range of international markets to capitalise on opportunities	Not addressed	Not Addressed	Defra
ID01: Risks to UK food availability, safety, and quality from climate change overseas	High	• Trade Agreements to consider environmental governance and exposure to climate risks to avoid undermining resilience • Adoption of multi-national regulatory structure in food commodity markets • Insurance mechanisms to protect domestic and international actors • Address food access inequality	Incorporating risk into contingency planning; research; DD for forest risk commodities through Environment Act; 2030 Strategic Framework (March 2023) advocates for rules-based international trade and investment system to boost resilience and reverse biodiversity loss and maintains level playing field to diversify and strengthen supply chains; strengthening the UK's position as a major market for environmental goods and services and using trade agreements to progress our climate and nature commitments; work of Met Office	Not Addressed/ Recognised but not addressed (as not mentioned in NAP3) Key policy opportunities in next two years: Medium (new food security strategies)	Defra

4.2 FINANCE: Scaling up investment in resilient infrastructure and nature-based solutions in Emerging and Developing Economies (EMDEs)

There is a broad consensus that both the quality and quantity of international finance for climate and nature must be increased, as reflected in the recent UK commitments to the Glasgow Financing Pact at COP26 and the Global Biodiversity Framework. An additional $3.9 trillion is estimated to be needed annually to meet the SDGs, with up to $366 billion per year for adaptation in EMDEs (UNEP, 2023a), and approximately $542 billion per year by 2030 to meet the Rio targets (including biodiversity) (UNEP, 2023b). As demonstrated in Chapters 2 and 3, increasing finance for resilience and nature in EMDEs can contribute to UK systemic resilience and international development in multiple ways. These include such benefits as improving global food security, enhancing global pandemic resilience, fostering sound financial market development for local financial inclusion and economic development, as well as global financial stability.

In this report, we focus on resilient infrastructure and nature-based solutions. These are large topics, so this report offers only a brief review of some key issues as a primer for future analysis. Building systemic resilience encompasses more than just making infrastructure assets resilient or small-scale nature-based solutions projects. It is about ensuring the resilience of entire systems, particularly critical services provided by infrastructure systems such as transport and energy. This can also include ‘soft interventions’, such as insurance, institutional capacity building, early warning systems and contingency planning.

Of the trillions of pounds of investment required annually to mitigate and adapt to climate change and achieve the SDGs, most of this investment will be needed for infrastructure in EMDEs (NCE 2014, UNSG 2019). Mobilising investment in infrastructure and ensuring that current systems are resilient is a major challenge for many developing economies, particularly given their exposure to climate induced impacts and limited domestic resource pools (with restricted tax bases). Currently, in Africa alone, a minimum of $21.9 billion is needed annually for adaptation (GCA 2022). Even with adaptation financing doubling since 2016 (Carlin and Stopp 2022), the current levels remain too low to meet the needs. Since public budgets in both developed and developing countries are constrained, mobilising private investment is critical.

Of the total adaptation finance, only a fraction comes from the private sector. Around 3% of all climate finance, or $1 billion a year, originates from the private sector (World Economic Forum and PwC 2023; Buchner et al. 2021). Mobilising private finance for adaptation is therefore a priority for many international climate and development actors, including the UK. The UK has committed to ‘seek to use more innovative financial instruments to mobilise additional finance beyond our ODA, including considering the use of further guarantees and exploring the provision of hybrid capital to increase MDB lending’ (FCDO 2023). To strengthen systemic resilience both locally and globally, there is a pressing need for the private sector to: (i) adequately adapt their existing investments to local and transnational climate risks, and (ii) increase and accelerate investment in adaptation projects in the Global South.

Scaling up private finance for resilient infrastructure

Over 50% of adaptation finance is now directed towards infrastructure, up from about 30% in 2010. Figure 18 illustrates the increase and sectoral distribution of adaptation finance for infrastructure. This represents only a fraction of the total $2.9 trillion per year invested globally in infrastructure, much of which goes to EMDEs. This raises two key questions. First, how to ensure that the $2.9 trillion invested each year is resilient to climate change, and second, how to mobilise more resilient infrastructure finance to support the poorest countries that are unlikely to benefit from this $2.9 trillion.

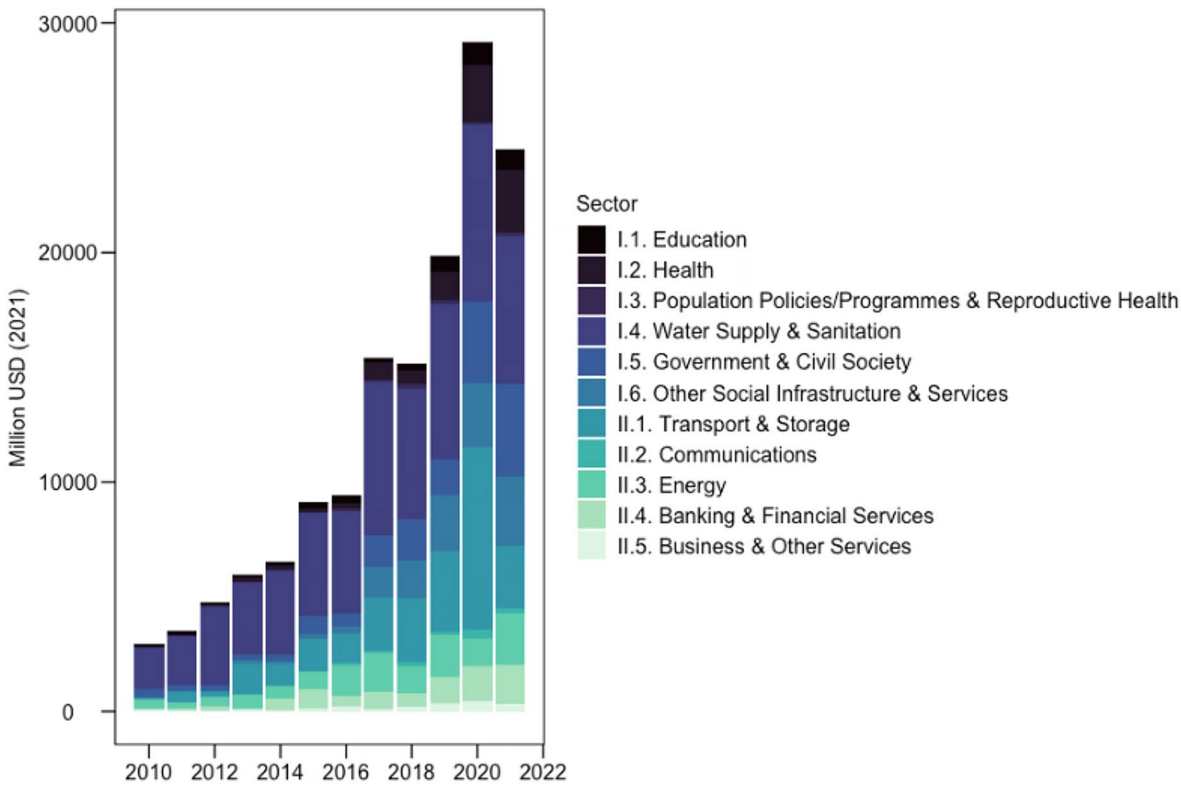


Figure 19. *Adaptation finance for infrastructure by sector.*
Source: OECD-DAC 2023.

Different market imperfections create barriers to private sector investment in infrastructure resilience and adaptation in EMDEs. First, there is significant uncertainty around the economic impacts of physical climate risks and TRCs (Prasad et al. 2022; Songwe, Stern, and Bhattacharya 2022). **Information barriers** occur when stakeholders and potential investors lack sufficient information regarding the nature and intensity of climate-induced risks for infrastructure across diverse geospatial contexts (Hall et al. 2019; UNDRR 2022c), as well as the benefits of infrastructure resilience, which are challenging to quantify. Several stakeholder consultations have shown that, in some cases, climate risks ‘are simply not on the radar of businesses’ (Cote and Mikaelsson 2023), hindering organisation-level investment in resilience, especially in supply chains.

Moreover, the OECD has identified **high risks for low returns** as one of the most important barriers to mobilising private capital for adaptation investments in infrastructure (OECD 2022). These typically involve high upfront costs and risks at different stages, including currency risks, coupled with low levels of and long-time horizons for return (e.g. Moser et al. 2019). For many types of infrastructure, the potential for user fee-based cash flows is limited, making it difficult to secure returns (ADB 2022). In cases where returns are possible and private investment is attractive, many private infrastructure investors may hold assets for a relatively short period (a few years), reducing the incentive to invest in adaptation unless driven by regulatory requirements or demands from multilateral funders. However, failing to adapt can lock societies into risks for decades – illustrating the classic ‘**tragedy of the horizons**.’

Often, climate change is primarily perceived as a risk amongst private actors, and climate adaptation subsequently representing a cost-reducing net return as opposed to an attractive area for profitable investments (Ahairwe et al. 2022).

It is also noteworthy that private sector actors keen to invest in adaptation find **a shortage of strong, bankable projects** as investment opportunities (OECD 2022). As noted in the UK International Development Strategy (2023), ‘more needs to be done to build a stronger pipeline of bankable projects, especially in low-carbon, climate resilient infrastructure (SDG 9)’ (FCDO 2023).

Institutional and regulatory barriers also exist, limiting the growth of private sector investment in adaptation. These barriers include shortcomings in existing institutional arrangements, governance systems and regulatory frameworks, which adversely affect business motivation (Pauw et al. 2022). Here, institutional competition, complex and layered bureaucracy, uncertain legislative environment, unclear distribution of liabilities in regulatory frameworks, and lack of conditions incentivising sector-specific investments in the policy environment represent some of the key issues (e.g. Bisaro and Hinkel 2018). There is also confusion around the very concept of 'resilience' in the context of infrastructure, which shapes the policy, practical and regulatory measures available to private investors (UNDRR 2022c).

Finally, there are potential **social and cultural barriers** that shape business motivations regarding adaptation, along with **internal capacity barriers**, such as poor internal management and operational capacity, which may hinder investments in adaptation (Pauw et al. 2022). Beyond investments in adaptation projects, adaptation measures at the organisational level (including climate risk assessments) can increase operational costs and reduce competitiveness, notably for SMEs (Mikaelsson, Dzebo, and Klein 2023).

Resilient infrastructure as a global public good

Another important driver of underinvestment in infrastructure resilience is the public good nature of this investment. The returns on investment in making infrastructure resilient come in the form of avoided failure and future impacts. While the investor pays, the bulk of the benefits are enjoyed by individuals and governments, generating a **principal-agent issue** (Hall et al. 2019). A study of 101 business cases on private investments in adaptation found that 79% of these cases provided benefits beyond the investor (Pauw, 2017). The public good element and social welfare objectives (i.e. positive externalities) in adaptation projects mean that private actors driven solely by return objectives tend to underinvest in adaptation (Bisaro and Hinkel 2018). This issue is particularly relevant for TCRs; a local infrastructure investor cannot derive a direct benefit from the benefits that investing in resilience provides to the wider global supply chains and trade networks.

Systemically important infrastructure, such as ports, provides another illustrative example. There is a clear global public good to investing in port resilience, a positive externality of private investment. However, there is currently no mechanism for the investor to internalise this global benefit. If private investors (or national governments) cannot internalise this positive externality, it could lead to underinvestment from a societal perspective.

We propose four potential solutions:

1. **Universal asset owners/large institutional investors** are better positioned to internalise the positive externalities from their investments in resilient infrastructure globally. They benefit from the reduced risks to other parts of their portfolios both directly and directly. Action by institutional investors could be encouraged through regulatory and supervisory requirements to assess and disclose risks and to fully capture risks within capital allocations and pricing.
2. **Regulatory or policy interventions** that require resilience standards on systemically important infrastructure or allow the externality to be internalised, for example, through a tax benefit or subsidy for investing in resilience.
3. **Smart credit ratings**: Infrastructure investments currently do not yield additional compensation in terms of higher credit ratings (Hall et al. 2019). This could be addressed by increasing transparency in ratings.
4. **Concessional finance for systemically important infrastructure:** There is a case for public investment to ensure the resilience of systemically important infrastructure, addressing the market failure, including through blended finance.

Mobilising investment in natural capital

The market barriers described above for grey infrastructure also apply to green infrastructure and nature recovery. A recent study by van Raalte and Ranger (2023) highlights that Nature-based Solutions (NbS) involve high risks and long investment times, with unclear return on investment on NbS. At the same time, information gaps exist due to the difficulty of quantifying the benefits of NbS investments. For instance, innovative NbS projects, such as those around green infrastructure (e.g. green water management, green buildings or mangrove and coral restoration for protection against natural hazards) face challenges in quantifying and monetizing the economic and social benefits they provide (see UNEP 2023 in van Raalte and Ranger 2023).The same global public good argument can be made for strategically important natural capital, where the private sector similarly lacks incentives to invest in preservation, and those four solutions above are equally relevant.

Blended finance: de-risking and crowding in private investment

Blended finance has emerged as a key tool to address investment barriers in climate finance in emerging markets, which include the lack of scaled investable products for private investors, a challenging risk-return profile, limited flexible capital for production innovation, demonstration and scaling, and a scarcity of climate finance actors at the transaction and market levels (Gregory 2023; WEF 2023).

Blended finance represents a structuring approach that strategically uses concessional capital and non-monetary assistance (e.g. technical assistance funded by public or philanthropic sources) to mobilise additional commercial capital for sustainable development projects. Broccolini et al. (2021) demonstrate that syndicated loans by multilateral development banks (MDBs), for example, can mobilise about seven dollars in bank credit for each dollar invested over a three-year period. Archetypical blended finance, as depicted in Figure 20, often involves the use of concessional (i.e. below market terms) funds within the capital structure of a project (1) to lower the overall cost of capital or provide an additional layer of protection to private investors (Convergence 2024). Often, this protection is further formalised through loan arrangements in which debt to concessional partner(s) is subordinated, while commercial debt is prioritised as senior. Concessional investors may also provide credit enhancement through guarantees or insurance on below-market terms (2), making the project's risk-return profile increasingly attractive for commercial investors (Attridge, Getzel, and Gilmour 2023).

Grant-funded technical assistance can also strengthen a project's commercial viability when direct provision of concessional funds to a project is not favoured by the providers (3). Similarly, grant-funded project design can lower the cost of capital when it is often scarcest (4), namely during the early, most uncertain stages of a project's lifespan (Convergence 2023).

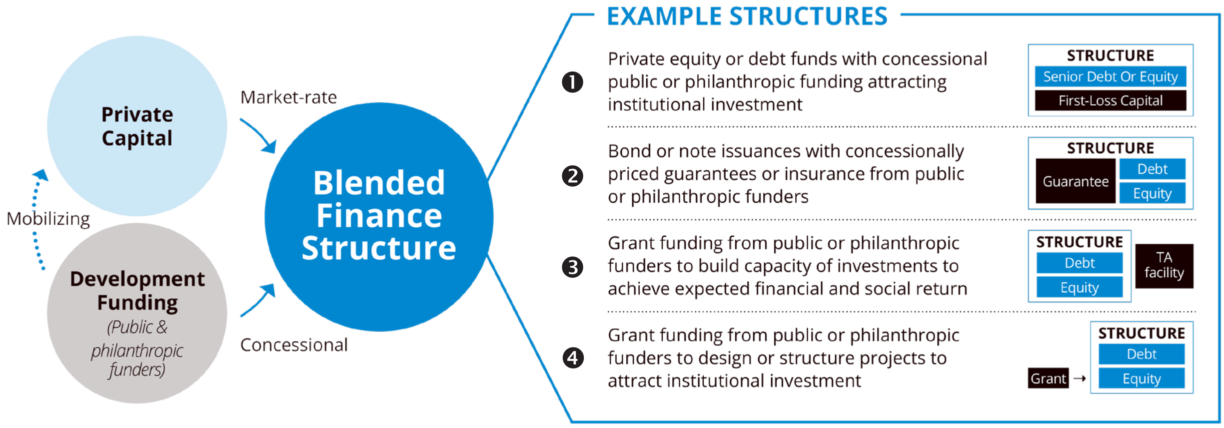


Figure 20. *Current landscape of blended financing structures and leveraging mechanisms*
Source: Convergence 2024.

Analysis of data captured by the OECD-DAC's creditor reporting system between 2010 and 2021 (Figure 21) reveals that adaptation finance in infrastructure has increased to almost $30 billion in 2020, representing a tenfold increase compared to 2010. Over the same period, debt finance emerged as the dominant form of financing in this area, at times accounting for up to two-thirds of total commitments. Grant finance has also increased, while equity and mezzanine finance have remained largely insignificant.

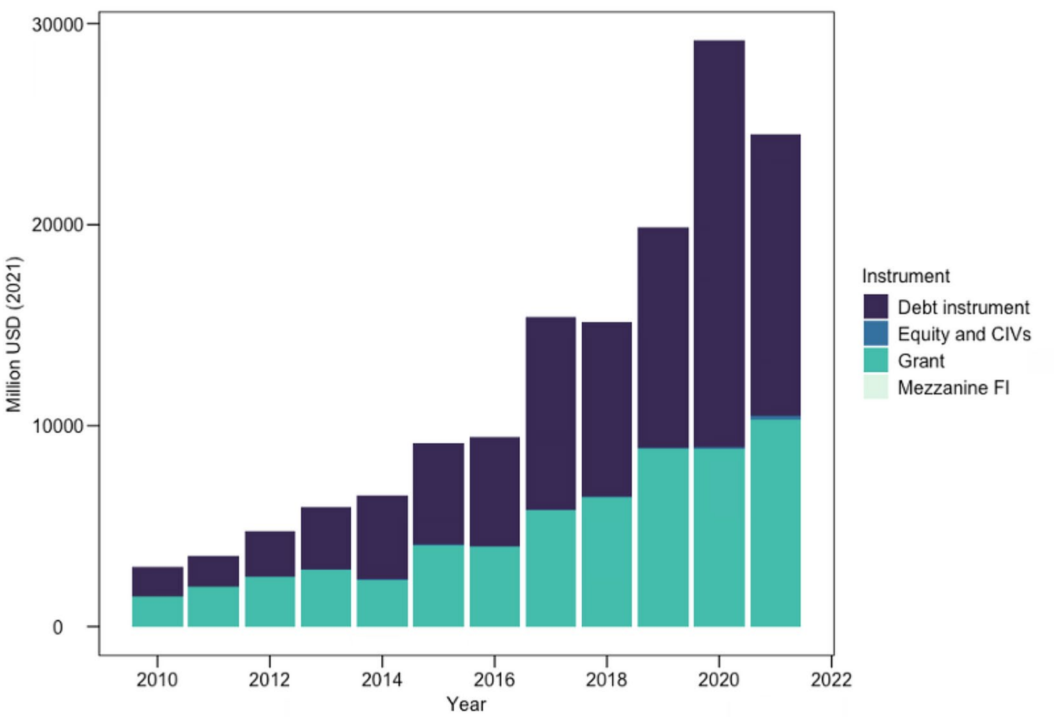


Figure 21. *Adaptation finance in infrastructure.*
Source: OECD-DAC 2023.

Box 4. Example of blended finance investment fund (EMCAF) strengthening the climate resilience of agriculture and medical supply chains

Established in 2021, the Emerging Markets Climate Action Fund (EMCAF) is a blended finance Fund of Funds created in partnership by Allianz Global Investors (Allianz GI) and the European Investment Bank (EIB). EMCAF provides highly catalytic early-stage equity financing to greenfield climate mitigation and adaptation projects in emerging and developing markets.

EMCAF's structuring makes it a form of blended finance with junior first loss tranches financed by public sector investors leveraging twice their value in senior investment. Allianz GI and EIB anticipate that adaptation and environment investments will account for 19% of total investments.

Investments by EMCAF to date include in ARCH Cold Chain Solutions East Africa Fund. ARCH invests primarily into greenfield assets in temperature-controlled supply chains. The project comprises storage, distribution and related services and activities to ensure a fully integrated value chain that can maintain a given temperature range for a wide range of products. Target clients are expected to be active mainly in the agriculture/food (~90%) and vaccines/medicine (~10%) sectors.

ARCH investments will help to reduce food waste from storage and transport, a particular issue in Africa's food supply chains, as well as increase food security, access to pharmaceuticals, and improve livelihoods for smallholder farmers. It is currently estimated that 30-50% of production is lost in sub-Saharan Africa along supply chains.

Source: https://www.eib.org/en/projects/pipelines/all/20190170; https://emcaf.allianzgi.com

The UK supports several vehicles that aim to mobilise private investment in infrastructure:

- **British Investment Partnerships (BIP)** is a public-private collaboration partnering with Sovereign Wealth Funds and capital markets, drawing on export finance support to de-risk and crowd in private sector finance. BIP's primary mission is to narrow the infrastructure investment gap in LMICs, aiming to mobilise up to £8 billion UK-backed financing by 2025. Under the BIP, the UK supports green transitions through promotion of reliable investments in infrastructure, and 'drawing economic partners closer to major free-market democracies' (HM Government 2023g). The BIP operationalises its key objectives through different government bodies and initiatives, including the BII (previously known as the Commonwealth Development Cooperation, CDC), MOBILIST and the PIDG, described further below.
- **The British International Investment (BII)** is the UK government's development finance institution, with the FCDO as its sole shareholder. The BII investments seek to maximise impact 'with a particular focus on our priorities of ESG, gender equality, climate change and business integrity.'[19] Infrastructure and climate constitutes one key sector within BII's broader mandate. BII's infrastructure-related work is largely focused on renewable energy generation, distribution and storage, but also includes ports and logistics, toll roads, water and sanitation, green transportation and urban infrastructure[20]. BII's infrastructure sector strategy involves a regional focus on sub-Saharan Africa and South Asia, and is founded on four principles, or 'investment themes': (i) create economic growth and jobs, (ii) tackle climate change, (iii) mobilise capital and catalyse private investments, and (iv) improve access to infrastructure and quality of life.[21]

19 See https://www.bii.co.uk/en/about/our-company/how-we-operate/how-we-make-investment-decisions/

20 See BII https://www.bii.co.uk/en/partner-with-us/sector-expertise/infrastructure-and-climate/

21 See BII/CDC Group https://assets.bii.co.uk/wp-content/uploads/2020/10/22160540/Infrastructure-sector-strategy.pdf

- **MOBILIST** (Mobilising Institutional Capital Through Listed Product Structures) is the UK's flagship public market mobilisation programme, which enables institutional investors to finance critical infrastructure needs in the Global South. It 'provides equity investment and technical assistance to support the listings of developing country assets through innovative financial products on major and local stock exchanges, mobilising both domestic and international investors.' 'MOBILIST recently anchored an asset-backed securitisation of $330 million in infrastructure loans and bonds from across Asia, the Middle East and Africa that is listed on the Singapore Stock Exchange (one of a number of MOBILIST partner exchanges around the world) and demonstrates the scale, transparency and governance benefits of public markets.' (FCDO 2023).
- **Private Infrastructure Development Group (PIDG)** was established in 2002 to mobilise and develop private sector finance for infrastructure in Africa and South and Southeast Asia. To date, the PIDG has mobilised $24.5 billion and committed over $5.3 billion to 211 infrastructure projects enabling access to renewable energy, water and transportation for over 220 million people (FCDO 2023).

The UK has also invested in infrastructure strengthening in LMIC through various **multilateral climate funds**. For example, it contributed to the Green Climate Fund with £1.44 billion in 2020–2023 and announced funding worth of £15 million for the Adaptation Fund at COP26. The UK participated actively also at **COP28** in 2023, where it pledged £40 million for the Loss and Damage Fund – a financial mechanism designed to compensate climate-vulnerable countries for their losses and damages (including those affecting infrastructure assets) from climate-change related natural disasters. The UK has also invested in the African Development Fund's Climate Action Window (CAW), which directs climate finance to support vulnerable countries' adaptation to climate change across six areas, including resilient urban and green infrastructure (HM Government 2023g).

Additionally, the two-year Glasgow-Sharm el-Sheikh (GlaSS) work programme resulted in an agreement on a framework for the Global Goal on Adaptation (GGA) at COP28. The GGA framework is based on seven thematic targets, two of which directly relate to infrastructure: (i) 'Increasing the resilience of infrastructure and human settlements to climate change impacts to ensure basic and continuous essential services for all, and minimizing climate-related impacts on infrastructure and human settlement', and (ii) 'Protecting cultural heritage from the impacts of climate-related risks by developing adaptive strategies for preserving cultural practices and heritage sites and by designing climate-resilient infrastructure, guided by traditional knowledge, Indigenous Peoples' knowledge and local knowledge systems.'[22]

Furthermore, the UK has made **direct bilateral investments** in strengthening climate resilience, as exemplified by the case of Dominica. This is an example of **resilient recovery and reconstruction financing** that can help build the resilience of infrastructure for the long-term. The UK has been a leading support to Dominica's recovery from the impacts of Hurricane Maria in 2017, which caused $1.3 billion in damages. Seeking to become the world's first climate resilient nation, Dominica has benefited from UK investments into the Climate Resilience Execution Agency, development of geothermal energy, climate resilient health care centres and road infrastructure (UK Secretary of State for Foreign, Commonwealth & Development Affairs 2023).

22 See https://unfccc.int/sites/default/files/resources/cma2023_L8_adv.pdf

Box 5. Room2Run

The Room2Run is an innovative PPP collaboration launched in 2021 between the UK and the African Development Bank (AfDB) – involving DFIs and the insurance market. The initiative provides a $2 billion guarantee to the AfDB against the risk of loan defaults, FCDO covering $1.6 billion, and $400 million being covered by the City of London insurance industry, namely AXA XL, Axis Specialty, and HDI Global Specialty. The initiative is aligned with AfDB's general balance sheet optimisation objectives and seeks to unlock an additional $2 billion worth of climate finance for Africa by 2027, split equally between mitigation and adaptation projects.

The initiative's first two projects were operationalised in 2023, with focus on water infrastructure resilience. These include a water sanitation project in Senegal (€37 million) providing safe water and sanitation services with a reach of 1.45 million people, and a wastewater project in Egypt (€80 million). The latter supports the second largest wastewater treatment plant in the world in terms of capacity – the Gabel El Asfar Wastewater Treatment Project – with the aim of expanding arable land by 70,000 acres. The project is expected to benefit 5 million people through improved food security, access to sanitation services and job creation.

Source: African Development Bank Group 2023; FCDO 2023.

Strengthening requirements for Environmental Impact Assessment

Infrastructure investments need to be both climate-resilient and minimise ecological risks, to sustainably yield economic, social and environmental benefits. As highlighted in the literature review section of this report, infrastructure for transport systems drive environmental degradation and can contribute to increased TCRs. Development agencies have utilised environmental safeguard instruments, including the Environmental Impact Assessment (EIA), while governments have introduced 'protected areas' to limit potential damage caused by infrastructure investments. However, as Damania et al. (2017) highlight, investor influence and commercial interests often override conservation concerns. To address this, new pre-emptive approaches that draw on econometrics, biology and geographic information systems are needed to ensure infrastructure investments create economic benefits without damaging ecological 'hotspots'.

Since 2023, all new bilateral ODA has been aligned with the Paris Agreement to ensure that development finance is consistent with climate and natural objectives (HM Government 2023a). Additionally, the World Bank Group has developed a Resilience Rating System (RRS) – first piloted in 2021 – to guide investment decisions, attract increasing finance to climate-resilient projects and support the design of such projects with adequate risk reduction measures, particularly in the infrastructure sector. The RRS evaluates and rates the resilience of a project and the extent to which it contributes to resilience ('resilience through the project'). Crucially, the RRS captures resilience impacts beyond the immediate boundaries of a project and encompasses broader effects such as those on institutional strengthening (World Bank 2024). The RRS is now being used to assess World Bank operations and IDA20, as well as other climate risk screening by public and private sector actors.[23]

23 See https://www.worldbank.org/en/topic/climatechange/brief/resilience-rating-system-rrs

Box 6. Port Case Studies: Manzanillo, MEB Cartagena and Banjul

The following case studies of climate-resilient port infrastructure investments illustrate the importance of assessing and incorporating both direct and indirect impacts, taking into account multiple stakeholders, as well as the importance of the discount rates and investment return timeframes which vary according to public-private ownership arrangements. In particular, the internal rates of return for investments were higher for longer time periods, given the heightened impacts of climate change and the resulting operational losses.

Project documents and other supporting literature were used to build representative cost-benefit analyses and inform the insights below.

Manzanillo (Mexico)
The port is administered by 'API Manzanillo', a federal agency created in 1994 with a 50-year concession to administer, promote, build and maintain it.

The assessment identified the following climate change risks as having the most significant financial impacts for the port:

- **Increased surface water flooding of the port**, causing disruptions to vehicle and rail movements and increased maintenance costs;
- **Increased intensity of rainfall**, causing sedimentation of the port basin, impacting terminal access and increasing required maintenance dredging;
- **Impacts of climate change on the global economy**, affecting trade through the port.

The recommended adaptation measures focused on (1) low-cost actions to build adaptive capacity to better understand and respond to climate change challenges (no regret) and (2) priority adaptation measures to address the most significant risks, including upgrading the port drainage system (Drain 3) and adding sediment traps in all drains.

MEB Cartagena (Colombia)
The port is privately owned. Muelles El Bosque (MEB) was established in 1992 and the company currently holds a concession from the Government of Colombia to develop and manage the port until 2032. MEB consists of two entities – Terminal Maritimo Muelles El Bosque, which holds the concession, and Muelles El Bosque Operadores Portuarios, which provides port operations.

The assessment identified the following climate change risks as having the most significant financial impacts for the port:

- flooding of the causeway and the associated disruption to vehicle movements, and
- changes in demand, trade levels and patterns.

Goods storage was also discussed as a moderate risk.

The recommended adaptation measures were (1) raise the height of the causeway road, (2) pave the port's unpaved areas, (3) improve drainage, (4) develop knowledge of and/or trade in climate resilient commodities, (4) manage energy costs for refrigeration, (5) protect goods from seawater flooding, and (6) contract additional insurance.

Banjul (The Gambia)

The Port of Banjul is fully operated and owned by Gambia Port Authority (GPA), a state-owned entity created in the Ports Act (1972) to operate the ports of the Gambia on a commercial basis. Along with the exploration of financing from development partners, AfDB and European Investment Bank, part of the 4th expansion of the port is planned to be developed and financed under a 15-year concession agreement. In this scenario, a project company (formed of a private investor chosen by the government, and with GPA holding a minority stake) will enter a design, build, finance, operate, maintain and transfer back the new container terminal.

Climate risk assessments and vulnerability stress tests were conducted to support the $115 million Port of Banjul 4th Expansion Project.

Box 6 continued. Port Case Studies: Manzanillo, MEB Cartagena and Banjul

Extreme sea level rise and river discharge, extreme temperatures and extreme precipitation were determined to be high-level risks. These climate risks are likely to impact port operations, as opposed to posing a high risk to physical assets. Given the high risk to operations, the total economic risk was estimated to be very significant. In addition to building climate resilience, the project aims to improve the port's capacity and operational efficiency.

Recommended actions include (1) climate resilient jetty extension by 345 meters to accommodate three ships simultaneously instead of one, (2) expand the container terminal area by 22,000 m^2, (3) climate proofing and widening the port access road, (4) procure a new green ferry for Banjul/Barra crossing points, and (4) set up an early warning system for climate hazards.

Discussion

Ports are complex operations, with a wide variety of infrastructure and technical components, distinct ownership and management structures, connectivity to multiple sectors and supply chains, and embeddedness in the global trade economy. Nevertheless, the climate risks and adaptation priorities are typically seen from the perspective of the port operator, despite the importance of other critical stakeholders including port clients, such as shipping companies and other enterprises, municipal and national government employees, local community members, and international trading partners and markets.

In the cases of the Port of Manzanillo in Mexico and MEB in Colombia, the ports are operated by entities under concessions granted by the government. Only a few decades remained on the concessions, which significantly limited the period for returns on investments in climate resilience. Moreover, in several instances, certain climate change-related impacts were not considered or estimated as they fell beyond the timeframe of the concession, despite the potential for severe disruptions and costs in the future. Select investments, e.g. quays, were disregarded if determined to be unnecessary in the near-term or not aligned for the end-of-life of infrastructure.

In the case of MEB, representative cost-benefit analyses found the internal rate of return (IRR) for the adaptation projects to be around 5.4% when considering only the costs and benefits up to 2030 – two years before the end of the concession – and a discount rate of 10%. However, extending to 2050 – less than 20 years after the concession is due to end – generated an IRR of above 8%. Moreover, the option to raise the port's patio and warehouse area is given little consideration in the assessment as the most significant costs related to damage of goods are expected after the concession period ends.

Privately funded projects tend to use higher discount rates than those that are publicly funded. For MEB and Manzanillo, the discount rates were 16% and 10%, respectively, compared to a typical government rate of 3.5%. In the case of MEB, the IRR of the two most critical adaptation actions going out to 2050, at a 16% discount rate, was just below 3%, assuming accelerated sea level rise. When using a discount rate of 3.5% for the same period and estimated costs and benefits, the IRR is significantly higher at 15.3%.

Finally, investment decisions taken for the benefit of the port operator may leave out significant costs and benefits to other stakeholder groups and the wider economy. For example, in the case of Manzanillo, each hour of terminal downtime costs API Manzanillo an estimated $4,000, whereas the terminal enterprises, which lease space in the port, lose more than three times that amount.

The above analysis shows the current situation is leading to underinvestment in climate adaptation and resilience for the world's ports. If the proposed projects were assessed against longer time periods, used lower discount rates, and considered costs and benefits to more stakeholders and the wider economy, the result would be substantially higher returns and stronger investment rationales.

Source: Multiple sources and authors' own calculations drawing on case study information.

4.3 DATA: Strategic information systems

Data serves as the foundation for improving the management of TCRs. This includes data for risk assessment, stress testing and scenario analysing; data to identify and assess vulnerabilities in real-time to guide solutions; and early warning systems and longer-term projections to enable earlier action, planning and investment in resilience. As such, investing in open and transparent information can be an important public good for governments.

Risk assessment

Improving access to data related to physical risks and TCRs is essential to inform **risk management** by government and the private sector. For example, the International Risk Governance Council (IRGC) incorporates data throughout different stages of risk management processes, including: risk (i) pre-assessment (e.g. problem definition, early warning systems); (ii) appraisal (e.g. exposure and vulnerability assessment, stress tests); (iii) characterisation and evaluation (e.g. assessing the severity of risks); (iv) management (option assessment and evaluation) (Schweizer and Renn 2019; UNDRR and CDRI 2023).

To conduct accurate risk assessments, it is crucial to understand the actual risks that the UK faces and their characteristics – what they are, when and where. This requires more and better-quality data at a more granular and local (country) levels regarding supply chains, the environmental services that the UK depends on for imports and exports and other dimensions of the global economy. However, it also requires improved approaches at global scale that can capture the interconnected nature of global systems (Ranger et al. 2022). Currently, many models do not capture these interconnections between systems. The Third Climate Change Risk Assessment identified the lack of data to fully assess risks of TCRs, and this has been the focus of a number of initiatives, including the EU-funded CASCADES programme and the Oxford Martin Systemic Resilience Initiative at the University of Oxford. The government's recent Critical Supply Chains Strategy is a good example of how to identify risks and build strategic responses. The government's SitCen represents another example enabling the generation of 'independent' evidence on cascading risks and shocks that can impact the UK to inform policymaking.

However, recent climate stress testing and scenario analyses by financial institutions have revealed significant challenges in assessing – and consequently pricing and managing – risks from TCRs. The scenarios used by most financial institutions to date do not include TCRs, substantially underestimating such risks (FSB and NGFS 2022). Indeed, the current generation of scenarios produced by the Network for Greening the Financial System, as well as those developed by the Bank of England as part of the UK's 2021 Climate Biennial Exploratory Scenario (CBES),[24] did not include TCRs at all (Ranger, Clacher and Bloomfield 2023). Findings from recent research by Trust et al. (2023) emphasise that British financial institutions lack a sufficient understanding of forecasting models to estimate economic impact of climate change, leading to a severe underestimation of actual risks (see also Ahairwe et al. 2022). Studies such as Avery, Ranger, and Oliver (2024) attempt to bridge this gap by developing narrative scenarios that capture a wide range of possible TCRs and employing a combination of simple and complex models to quantify them.

24 See https://www.bankofengland.co.uk/stress-testing/2022/results-of-the-2021-climate-biennial-exploratory-scenario

Monitoring and early warning systems

Dynamic risk data, in the form of real-time risk monitoring and early warning systems, is crucial for informing early action. For example, in supply chain analytics, the government is generating new intelligence through the Global Supply Chains Intelligence Programme (launched in March 2021), combining different government and industry data to identify risks. The government is also drawing on data produced by UK embassies, missions and consulates across over 100 overseas posts. Additionally, the Ministry of Defence is developing a 'supply-chain illumination capability', which utilises predictive analytics and monitoring specifically around defence-related supply chains. The government is also undertaking supply chain stress tests through a collaborative exercise involving government, (international) partners and business representatives (HM Government 2024).

The case studies in Chapter 4 point towards the need for more comprehensive and integrated risk monitoring and warning systems. As part of the Oxford Martin Systemic Resilience Initiative, researchers have been working with the IMF to develop novel monitoring systems for supply chain disruptions using real-time monitoring data (Box 7).

Box 7. Portwatch

PortWatch is an online platform that offers cutting edge analytical tools to assess the domestic and international trade impact of actual and future disasters. It allows policymakers, private sector actors and the general public to monitor and simulate disruptions to maritime trade due to climate extremes and other shocks. Using satellite-based vessel data and big data analytics, the platform includes timely indicators on actual and expected trade disruptions in affected countries; simulation of international spill-over effects from actual and hypothetical disasters; and climate scenario analysis facilitating the identification of vulnerabilities within the maritime trade network. The evaluations are informed by modelled risk estimates at 1,400 ports worldwide for different types of disasters (cyclones, floods and earthquakes).

Moreover, the platform offers a monitoring system to track activity and trade at each of the 1,400 ports and 13 maritime chokepoints in near real-time and at a daily timestep. This allows decisionmakers to track economic activity and emerging crisis.

Portwatch is a collaborative project between the IMF and the Environmental Change Institute at the University of Oxford. For further information, visit https://portwatch.imf.org/.

Forward-looking risk information

For financial institutions and infrastructure investors, forward-looking risk information is essential to ensuring that climate risks are appropriately factored into investments and that risks are priced and managed appropriately. For example, Ranger et al. (2022) draw attention to the ways in which the finance sector can be galvanised to invest in infrastructure resilience through open, comparable and common data and metrics. These include improved ability to do high level screening and more detailed assessments of portfolios and projects, to compare climate exposure and performance of assets, and to develop adaptation plans. Disclosures of risk and adaptation plans enhance transparency, leading to improved decision-making by both investors and governments. This, in turn, helps guide capital flows to align with adaptation and nature-related goals. More granular risk information can also improve the valuation of the systemic benefits of investment and enhance risk pricing amongst banks and insurers, thereby creating a financial incentive for investing in resilience.

4.4 TRADE AND SUPPLY CHAIN RESILIENCE

The CCRA3 made several recommendations to integrate resilience within trade policy and strengthen domestic supply chain resilience. Similarly, European countries are increasingly looking to trade policies to strengthen the supply chain resilience. These policies include: (i) *diversification* (expanding sources of supply to limit dependencies); (ii) *stockpiling* (creating surge capacity by storing vulnerable goods); and (iii) *onshoring* (increasing domestic production) (Cote and Mikaelsson 2023). The CASCADES research programme recommends the formulation of trade resilience strategies that account for societal resilience alongside broader trade objectives. These strategies would emphasise long-term, stable trade partnerships that maximise mutual resilience, as well as 'dynamic responses in a more volatile world of cascading risk.' The latter could include new trade crisis response plans and approaches to strengthen preparedness through existing informal trade policy forums (e.g. Transatlantic Initiative on Sustainable Trade) (Townend et al. 2023).

The UK could look to address TCRs explicitly within new trade agreements by incorporating resilience clauses, thereby avoiding locking-in unsustainable practices through the perpetuated lack of attention to environmental and climate risk-related matters (Chatham House 2022; see also Climate Change Committee 2021). Balancing the pros and cons of these different strategies requires a long-term, holistic approach to resilience. Onshoring, for instance, may reduce vulnerability to TCRs in highly globalised supply chains but could also add climate stress in regions closer to home (Cote and Mikaelsson 2023). Diversifying supply chains for critical commodities may be necessary to reduce UK vulnerability to TCRs (HM Government 2021). At the same time, there is a need to consider the development of new trade partnerships to meet future needs – such as around green hydrogen. The 2021 National Resilience Strategy highlights the UK's market-first approach to building resilience in critical supply chains, notably by increasing diversification of supply through international trade (as well as investments in strategic reserves, expanding national production and promoting a rules-based, free and fair global trading system) (Cabinet Office 2021). Some of the market-led strategies the UK is already employing support this objective – for example, lowering trade barriers, targeted trade promotions and multilateral global supply chain vulnerability assessments (e.g. HM Government 2021).

Diversifying away from supplies from climate-vulnerable countries may seem beneficial in the short term but can prove unsustainable by exacerbating vulnerabilities in the Global South and leading to greater long-term risks (Townend et al. 2023). The UK seeks to 'encourage imports of goods and services from low- and middle-income countries to support their development and make UK supply chains more diverse and resilient to climate change' (see 4.11 in UK Secretary of State for Foreign, Commonwealth and Development Affairs 2023). Partnerships that support mutual resilience offer a more sustainable long-term solution. For instance, the government is utilising Free Trade Agreements (FTAs) to support investment flows in both directions, which is expected to 'support greater supply chain resilience as businesses can more easily set up or expand production at home and abroad' and increase transparency regarding licensing requirements in supply chains (HM Government 2024). Through the Developing Countries Trading Scheme (DCTS),[25] launched in 2023, the UK provides preferential trading agreements to 65 LMICs, lowering import costs and diversifying supply chains. The UK may also deploy trade rewards for countries that refrain from imposing export restrictions. Additionally, the UK is leading efforts to strengthen supply chain resilience through its multilateral engagement at G7 and G20 summits, and the OECD.

In terms of managing supply chain-related risks, the UK has established a Critical Imports Council and now seeks to launch new governmental structures to oversee and evaluate the delivery of the Critical Imports and Supply Chain Strategy. Designated Lead Government Departments will develop

25 DBT 2023, see https://www.gov.uk/government/collections/trading-with-developing-nations#:~:text=The%20Developing%20Countries%20Trading%20Scheme%20(%20DCTS%20)%20entered%20into%20force%20on,order%20to%20support%20their%20development

sector-specific contingency plans, while the Cabinet Office Briefing Rooms (COBR) Unit will address complex, cross-cutting shocks. Other key structures include the Critical Minerals Intelligence Centre, launched in 2022 and led by the British Geological Survey, which analyses critical mineral supply and demand. The National Energy System Operator (NESO), in turn, will ensure the supply of gas and electricity and lead gas supply security assessments. Enhancing the capacity of these structures to detect, monitor and manage TCRs – while ensuring effective collaboration – is critical.

4.5 CORPORATE AND FINANCIAL REGULATION

Increasing and strengthening the regulatory frameworks and standards for risk measurement, monitoring and disclosure represents a key axis of policy action for enhancing UK systemic resilience and mobilising increased investment into areas aligned with the UK's resilience objectives. As outlined by Ranger and Mullan (2022), decisions made by financial institutions today can lock in risks for decades, particularly in areas of infrastructure and natural capital. Investments in non-resilient infrastructure, for example, can undermine resilience both in EMDEs and in the UK. Similarly, financial flows that fund activities that destroy nature (e.g. deforestation) undermine global systemic resilience, as illustrated by our third case study.

Embedding physical climate risks and nature-related risks, impacts and dependencies into financial decision making is crucial – not only to protect the resilience of the economy and financial sector but also to mobilise increased investment that promotes resilience.

While substantial progress has been made in implementing corporate disclosure frameworks and integrating climate within financial supervisory and regulatory practices, emphasis on physical climate and nature risks has been weak, with TCRs almost entirely absent. Current regulatory frameworks to help strengthen risk management within the financial system are failing to encourage firms to assess, disclose and manage these risks. For example, while physical climate risks are integrated into the guidance of the Taskforce on Climate-Related Financial Disclosures (TCFD) and subsequently the International Sustainability Standards Board (ISSB), the TCFD progress report finds that fewer than half of all firms disclose physical risks (TCFD 2023). The practice across most financial institutions, and many standards and guidance bodies, is biased towards mitigation-related issues. Together, this means that the financial system is potentially unprepared for TCRs and fails to provide the necessary risk signals to encourage investment in resilience to TCRs across the wider economy.

Risk assessment, scenario analysis and disclosure practices must be upgraded to fully account for TCRs. Additionally, emerging transition plan practice should incorporate resilience and nature on equal footing with net zero – helping to incentivise adaptation investments (Ranger and Mullan 2022). Moreover, the UK is seeking to deliver campaigns to encourage responsible business practices in supply chains, particularly in critical mineral supply chains, through the UK programme for Responsible and Inclusive Business (FCDO 2023). There is potential to extend these efforts to include TCRs.

Creating market requirements for more transparency in supply chains is equally important. Currently, there are no legal requirements for private food companies to report on risks in their supply chains, despite significant pressures in the UK food sector (Climate Change Committee 2023). A recent stakeholder consultation included several clear asks from government, such as 'stronger statutory requirements and robust enforcement for the disclosure of physical climate risk exposure'; the introduction of clauses on climate adaptation into relevant legislative frameworks; and government provision of technical support and finance (e.g. grants or tax subsidies) 'to help smaller suppliers conduct climate risk assessments and implement adaptation solutions' (in collaboration with larger businesses, industry associations and social partners) (Cote and Mikaelsson 2023; see also West 2021). The UK government can further promote climate resilient supply chains through its own public procurement systems, with standard setting or premiums for more climate-secure supplies (Cote and Mikaelsson 2023; see also recommendation by the UK Climate Change Committee).

4.6 GLOBAL RISK GOVERNANCE

The 2021 report of the House of Lords Select Committee on Risk Assessment and Risk Planning concluded: 'The world has changed into an increasingly complex web of interconnected systems which rely on disparate linkages across the globe… [Our] risk management system must adapt to ensure that we are prepared for the evolving extreme and systemic risks on the horizon.'

Since transnational climate risks are, by definition, borderless, global risk governance systems will play an essential role in ensuring coordination globally. A wealth of reports has recently emerged addressing gaps in risk governance (e.g. Jacobzone et al. 2020; Schweizer and Renn 2019; UNDRR 2022a; UNDRR and CDRI 2023). These reports propose different types of policy toolkits and processes to launch and implement risk governance and management systems. These include the processes around tracking and monitoring TCRs (and specific industries, supply chains, etc.), attributing accountability to designated actors and establishing information-sharing platforms with operators of critical infrastructure.

The CASCADES flagship report's recommendation 2.2 is to 'improve policy coherence to avoid harm and harness synergies' notably through inter-service cooperation. Policy incoherence also exists at the level of risk assessment frameworks, which vary across domains, and awareness of this issue is currently emerging at the international level, in organisations such as the WEF and the OECD (Chatham House 2022). Bolstering policy coherence is necessary not only in development policy, but also in broader foreign trade and security policies (Townend et al. 2023).

Box 8. Key Policy Recommendations of the CASCADES programme

CASCADES was an EU-funded programme that studied how the risks of climate change to beyond Europe might cascade into Europe, with the aim of supporting the design of a coherent European policy framework to address these risks. The initiative involved Chatham House, our partner on the policy recommendations developed for this study.

Thematic area	Recommendation	Actions
European institutions The EU needs to organise itself internally to be fit to handle the complex challenge of adapting to cascading climate risk.	**Recommendation 1: Build a European Civil Service fit for the cascades challenge**	**1.1** Build understanding of cascading climate risks **1.2** Establish risk ownership **1.3** Allocate resources and measure success **1.4** Develop a risk and resilience mindset
Climate diplomacy Coherent external action by the EU will facilitate the type of mutually beneficial partnerships that Europe needs to reduce vulnerability to cascading climate risk globally.	**Recommendation 2: Promote widespread resilience through external action**	**2.1** Meet and exceed adaptation finance commitments **2.2** Improve policy coherence to avoid harm and harness synergies **2.3** Increase technical assistance and political engagement with partner countries **2.4** Cooperate, lead and build trust within the international system
Trade The fragility of European supply chains trade is becoming apparent; the EU needs a trade system that builds and benefits from resilience.	**Recommendation 3: Take a strategic approach to resilient trade**	**3.1** Formulate a Trade Resilience Strategy for Europe **3.2** Expand the scope of the Critical Entities Directive **3.3** Support and facilitate supply chain 'restructuring' **3.4** Improve risk data and disclosure
Finance The low carbon transition already under way in the finance sector must also deliver resilience to cascading risks – public and private finance each have important and complementary roles to play.	**Recommendation 4: Promote transparency and accountability for broad resilience**	**4.1 Enhance cooperation, communication and disclosure** **4.2** Reform risk assessment and monitoring approaches **4.3** Mobilise innovative European finance for widespread resilience
Global governance Achieving resilience in Europe depends on whether the EU can navigate challenging geopolitical headwinds and re-establish its legitimacy and influence as a trusted leader on the global stage.	**Recommendation 5: Lead and support global governance of cascading climate risk**	**5.1** Champion global governance that is fit for a world of cascading climate risks **5.2** Support reform of international structures **5.3** Give climate security a home
European societies Individuals, communities, businesses and civil society must be prepared for disruption and be capable of contributing to resilience.	**Recommendation 6: Support strong societies for cascade resilience**	**6.1** Develop resilient local economies and communities **6.2** Reduce social inequality and strengthen cohesion **6.3** Engage and support wider society

Source: Townend et al. 2023, 7-8.

5. NEXT STEPS

This report has identified significant potential risks for the UK and global resilience associated with TCRs. It also finds that TCRs are already embedded within UK policy frameworks. Based on our own review, we find that the UK has already taken many steps to drive resilient infrastructure investment and enhance the monitoring of key global supply chains. However, as concluded by the Climate Change Committee, gaps remain. Globally, we have few systems in place to strategically assess transboundary climate (and environmental) risks in an integrated and comprehensive way. There are also few early warning systems and limited coordinated mechanisms to strategically tackle the drivers of risk and build systemic resilience before disasters occur. Furthermore, there is a significant shortfall in investment in resilient infrastructure – both grey and green – across the emerging and developing economies on which the UK depends.

A key conclusion from this policy analysis is the need for a holistic approach. Policy interventions need to address TCRs and systemic resilience across: (i) the different stages of the 'risk process' (risk identification, tracking, monitoring and risk management); (ii) different sectors and industries (trade networks; supply chains; the financial sector – banks, insurance companies, investors); and (iii) different scales and levels of governance – domestic, global and bilateral (i.e. EMDEs). Crucially, there is an acute need to balance and harmonise: (a) domestic versus overseas investments (e.g. multi- or bilateral aid, foreign policy), and (b) different types of policy 'tools' (e.g. development aid, trade policy around supply chains, regulating the finance sector, etc.).

The next step is to develop the evidence base and recommendations further.

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APPENDIX. Modelling methodology

Maritime chokepoints: methodology to determine traffic and trade dependencies

To capture the dependencies between chokepoints and country-level trade, the Oxford Maritime Transport (OxMarTrans) model is utilised.[26] This model predicts the allocation of maritime trade flows (based on bilateral trade data) on the maritime transport network, including the port and route taken, to determine the dependency between ports (and routes) and trade flow. In other words, it captures how trade between origin and destination are most likely being shipped across the global maritime transport network, including the port used for exporting, transhipment (if required) and importing. The resulting network consist of >2.1 million unique port-country pair combinations across >25,000 unique country pairs and 11 economic sectors, which capture the share of maritime trade between two countries going through specific ports and on specific routes. The base year considered is 2021.

Climate risks to ports: methodology to determine climate vulnerability at ports

To determine the climate vulnerability of ports, two datasets are combined: (i) port climate risks data and (ii) country trade dependency on foreign ports.

To determine the climate risks to ports, we use the output of a global multi-hazard risk analysis of ports, as described in Verschuur et al. (2023).[27] In this work, first, the location of different port terminals were mapped. Second, hazard data (e.g. cyclone, river flooding, pluvial flooding, coastal flooding, earthquakes) from various sources were processed and overlayed with the location of port infrastructure. Third, the vulnerabilities of port terminals to specific hazards were prescribed, and the downtime associated with damage to port infrastructure. Altogether this results in estimates of the downtime risk for each port individually (see above for definitions). Downtime risk is expressed as the expected annual downtime (EAD, in number of days per year) to the port operations as a whole. The EAD encapsulates both the downtime associated with reconstruction of damaged physical infrastructure, as well as downtime associated with the exceedance of operational thresholds (which do not cause damage). The EAD captures the downtime across the possible hazards (see below) and the range of hazard likelihoods (e.g. an event with an annual probability of occurrence of once every 1, 5, 10, 100 years, etc.).

The downtime risk is combined with the country's trade flowing through ports. For this, the outputs of the Oxford Maritime Transport model are used, which captures which ports are being used for exporting, importing, and transhipping UK maritime trade. The climate vulnerability of a port is then defined as the amount of UK imports or exports that are at risk of being affected due to a disruption at a selected port. Climate-vulnerable ports are those with a high risk of downtime and large trade dependencies.

Shocks to global grain supplies affecting the UK: methodology to model global food shocks to grain supplies

We model producer and consumer prices, supply, demand and trade flows using a newly developed global spatial price equilibrium model (SPEM). A SPEM is a multi-regional partial equilibrium model that links producers and consumers across regions. Producers and consumers are linked together via domestic or international trade, for which a certain trade cost must be paid. This includes all costs after leaving the farm, including storage, hinterland transportation, border and custom compliance, maritime transport, intermodal transfers, port fees, and imports tariffs. These have all been separately derived in previous work.

The SPEM model requires data on trade, transport and trade costs, prices, supply, demand, and information on the shape of the demand and supply curves (e.g. the demand and supply elasticities).

26 For more details see: https://www.nature.com/articles/s41467-022-32070-0

27 For more details see: https://www.nature.com/articles/s43247-022-00656-7

At the baseline, the SPEM model assumes that the decision to supply from certain regions is purely based on cost differentials of the total landed cost of goods (i.e. the cost to produce crops and ship them to the consumer). However, there are non-cost elements that determine where countries source from. Therefore, the model need to be calibrated on existing trade data to capture both cost- and non-cost related factors that determine the supply network of specific countries. In our SPEM model, we consider 177 countries for which we could collect all required data. These countries have interconnected competitive markets that trade a homogenous crop, with trade flows modelled on a directional basis. When referring to trade flows here, we mean both international trade flows and domestic supply. Producers in each country have a certain amount of supply to provide to the market (either domestic or foreign), which they sell at the highest possible price (following their supply curve). Consumers have a certain amount of demand for the good and buy goods at the lowest possible price (following their demand curve). Each country can trade with any other country, with a corresponding trade cost to source from domestic or foreign markets. In equilibrium, we can find the trade flows between countries that determine producer and consumer prices. For each country, total production and imports must match total consumption and exports in equilibrium.

We implement different types of shocks into the model, including production/yield variability, the Ukraine war, price shock, and trade bans:

- **Base**: For each country, we have 54 representative years of yield variability, resulting in years of higher or lower-than-average supply. We implement yield variability in the model by changing the initial condition of the total supply and shift the supply curve. A positive supply shock movies the curve to the right, while a negative supply shock moves it to the left.
- **Tail risk**: We also develop a tail-risk scenario, in which the UK and the five largest importers to the UK face a breadbasket failure. We first estimate, per country, the 1st percentile yield reduction over the 54 years and implement a simultaneous supply shock to these five countries, all else equal.
- **Ukraine war:** For this scenario we make three adjustments in the model. First, we lower the supply for Ukraine to 60% of its baseline supply, in line with observed supply reduction in 2022–23. Second, we increase the trade costs to Russia (to cover a surge in insurance costs to trade with Russia). Third, we implement a version of the blockage of the Black Sea ports by increasing the trade costs to and from any country that is not part of the European Union and the United Kingdom, to capture the difficulty of sourcing Ukraine's exports via sea.
- **Price shock:** A price shock is introduced to capture the increase in fertiliser, pesticide and diesel costs due to supply issues, as well as the energy crisis over the last few years. We follow a similar methodology as in Verschuur et al. (2023)[28] and estimate, for each country, the share of the fertiliser, pesticide and diesel costs in the total crop production cost. We then impose a price shock to these three inputs, increasing fertiliser and pesticide costs by 200% and diesel costs by 100%. This yields a production price increment, which we assume is being passed through to the consumer.
- **Trade bans.** We utilise a global database (https://www.globaltradealert.org) on trade-related interventions taken by countries from 2022 onwards. This database covers which countries impose trade restrictions, which countries are affected by them, and for which commodities these restrictions apply. We extract all import and export trade bans implemented (hereafter trade bans) and encoded this in the model by imposing higher trade costs between these countries.
- **Compound shock.** In the compound shock, or polycrisis, scenario, we include all previously mentioned shocks at the same time to evaluate their compound impacts.

For each shock scenario, we evaluate the consumer prices variability for the UK. Moreover, we can look at the correlation between UK consumer prices and imports from UK supplying countries. The latter can help identify which countries are beneficial for the UK in terms of prices, and hence securing more (stable) supplies from these countries can help longer term food availability.

28 See https://www.researchsquare.com/article/rs-3289367/v1

Future green ammonia imports to the UK: methodology to model future green ammonia levelized costs for the UK

The cost of green ammonia production is estimated using a mixed-integer linear programming (MILP) model, which optimises the equipment-sizing and operation of a green ammonia plant for historic wind and solar profiles. The model optimises the levelised cost of green ammonia (LCOA) production. Detailed descriptions of the model are available in Salmon & Bañares-Alcántara (2021, 2023). National average LCOA estimates are derived taking the weighted average of sample production locations in each country at 1-degree spacing and the maximum theoretical production capacities at those sites. Cost and efficiency data for renewable energy generation, water electrolysis, batteries, hydrogen fuel cells, air separation, and Haber-Bosch synthesis are considered. Cost trajectories for various technologies are adopted from Way et al. (2022). Regional future costs of capital, capturing the differences in the weighted average cost of capital between production regions, are included based on data from Ameli et al. (2021). The cost assumptions for various technologies involved in green ammonia production, such as renewable energy generation, water electrolysis, batteries, hydrogen fuel cells, air separation, and Haber-Bosch synthesis, are based on current market prices and anticipated cost reductions over time. Future cost trajectories for these technologies are considered to reflect expected advancements and economies of scale. Feasible production capacity at each location is determined based on the total land available, considering land-use availability and land competition, and accounting for protected areas and steeply sloping land. Production from offshore energy resource is not included in these results, as model results indicate that, without subsidies, it would be around two times more expensive than entirely land-based production, given a comparable weather profile and the relatively good availability of on-land production sites.